UNIVERSITY OF ALBERTA

RELEASE FORM

NAME OF AUTHOR: Mark Barling

TITLE OF THESIS: The geomorphology and alluvial history of Matzhiwin Creek, a small tributary of the Red Deer River in southern Alberta.

DEGREE: Master of Science

YEAR THIS DEGREE PRESENTED: Fall 1995

UNIVERSITY OF ALBERTA

# The geomorphology and alluvial history of Matzhiwin Creek, a small tributary of the Red Deer River in southern Alberta.

By

Mark Barling ©

A thesis submitted to the Faculty of Graduate Studies and Research in partial fulfilment of the requirements for the degree of Master of Science.

Department of Geography

Edmonton, Alberta
Fall 1995

UNIVERSITY OF ALBERTA

FACULTY OF GRADUATE STUDIES AND RESEARCH

The undersigned certify that they have read, and recommend to the Faculty of Graduate Studies and Research for acceptance, a thesis entitled THE GEOMORPHOLOGY AND ALLUVIAL HISTORY OF MATZHIWIN CREEK, A SMALL TRIBUTARY OF THE RED DEER RIVER IN SOUTHERN ALBERTA submitted by MARK BARLING in partial fulfilment of the requirements for the degree of MASTER OF SCIENCE.

**Abstract**

This study examines the postglacial alluvial chronologies of some of the rivers and creeks in central and southern Alberta. It provides information on the timing and possible causes of long term stream adjustments which have occurred. During early postglacial times, changes in local baselevels and the effects of isostatic recovery were most likely the dominant controls on stream behaviour. In the Red Deer River, rapid downcutting in the early postglacial period resulted in over 70m of incision in the downstream reach of Matzhiwin Creek, a tributary stream, in response to the lowering of local baselevel. A steep, convex-up profile developed in Matzhiwin Creek as it was unable to incise as rapidly as the Red Deer River given its smaller drainage basin size and discharge. Following deep incision in the downstream reach, alluvial fan deposits formed along the valley sides indicating a probable trend towards more arid conditions. Truncation of the fan deposits, possibly around 5.0ka BP, occurred in response to either renewed downcutting by the Red Deer River or as a result of wetter climatic conditions.

Alluvial terraces in the upstream reach of Matzhiwin Creek reflect episodes of aggradation and incision during the mid to late Holocene. In places, younger terraces have been incised into an undated, but older valley fill. Material obtained from terrace alluvium in Matzhiwin Creek (and from other creeks in central and southern Alberta) which has been radiocarbon dated indicates major episodes of stream aggradation and incision post 4.0ka BP. Widespread stream aggradation occurred around 3.2-2.0ka BP and 1.8-0.3ka BP with incision occurring around 2.0-1.8ka BP and post 0.3ka BP.

Episodes of widespread stream aggradation and incision in tributary creeks may indicate the influence of large-scale climate change on stream behaviour in the mid to late Holocene. However, the exact nature of the effects of

climate change on stream processes is unclear. Widespread incision may have been triggered by a trend towards climatic conditions which favoured greater runoff and an increase in the magnitude and frequency of floods capable of stream incision and subsequent terrace formation.

**Acknowledgements**

This thesis could not have been completed without the help of a great number of people to whom I am greatly indebted and honoured to have known. I thank Dr Hazel Faulkner for all her help, advice and encouragement in the first place. My supervisor, Dr Ian Campbell, was always helpful and how he put up with me I shall never know. I especially thank him for allowing me the wonderful opportunity of studying in Canada and the experience of living in Dinosaur Provincial Park, something I shall never forget. Thanks are also due to Dr Bruce Rains from whom I learnt a great deal, and perhaps most importantly, how little I do know. Particular thanks are due to the Eastern Irrigation District and the landowners along Matzhiwin Creek - especially Mr. Ed Mattheis - for giving me permission to have access to their property. Without their agreement the research could not have been completed.

I also have to say a big thanks to the following who made my time so enjoyable: Skidz, Jeff, Vince, John, Lee, Puspa, Celina, Anne and of course the Lathams. Finally, but certainly not least, I would like to thank Christine who taught me to follow my dreams.

Table of contents

# List of tables

List of figures

# 1.0 Introduction

Alluvial terraces along river systems reflect changes in baselevel and variations in discharge and sediment yields and can be geomorphic indicators of postglacial environmental changes. Periods of widespread channel aggradation or incision may therefore reflect change in external variables such as baselevel, climate or isostatic recovery.

In Chapter 2, postglacial alluvial chronologies of two main river systems and selected creeks in central and southern Alberta are reviewed. Alluvial chronologies have been established on the basis of $^{14}C$ dated material obtained from terrace deposits and stratigraphic information. The response of fluvial systems in this area to postulated postglacial climate change can be examined by comparing periods of widespread stream aggradation and incision to the palaeoclimate record which has been interpreted for the region.

Chapter 3 presents a detailed geomorphological study of the stratigraphy of stream terraces and alluvial deposits along Matzhiwin Creek, a tributary of the Red Deer River in southern Alberta. A postglacial chronology is reconstructed in which periods of stream aggradation and incision are identified. The alluvial chronology for Matzhiwin Creek is compared with stream aggradation and incision phases which occurred in surrounding creeks containing dated terrace deposits. Periods of widespread stream aggradation and incision may be related to baselevel changes associated with the Red Deer River, postglacial climate change and the effects of isostatic recovery in the early postglacial period. In the final chapter conclusions are made summarising the results from Chapters 2 and 3.

## 2.0 Postglacial alluvial histories of fluvial systems in central and southern Alberta and possible causes of long term fluvial adjustments.

### 2.1 Introduction.

Streams adjust their channel morphology and their behaviour in the long, medium and short term to variations in runoff and sediment yield, and baselevel changes (Schumm and Lichty 1965). Because climate is considered to be the dominant influence on runoff and sediment yield both directly through precipitation, and indirectly through vegetation (Knox 1983), widespread fluvial adjustments involving channel aggradation and incision have often been attributed to the effects of large-scale climatic change (Brakenridge 1980;Knox 1983). However, even if episodes of stream adjustments are triggered by a climatic change there is no clearly demonstrated, systematic and direct relationship between direction of climate change and the type of fluvial response. In the northern Great Plains episodes of Holocene stream aggradation have been attributed to both precipitation increases and decreases (McDowell 1983).

River valleys in central and southern Alberta contain evidence of postglacial fluvial adjustments in the form of alluvial terrace remnants. Terrace sequences in this area whose chronologies have been established on the basis of $^{14}C$ dating reveal general patterns of time-synchronous aggradation and incision; two major periods of aggradation occurred between ca.3.0 - 2.0ka BP and ca.1.8 - 0.3ka BP (Rains and Welch 1988;Campbell and Evans 1990;Campbell *et al*.1993;Rains *et al*.1994). However, studies of the postglacial evolution of the North Saskatchewan River near Edmonton, Alberta, have revealed very different alluvial chronologies between the main stream and some of its tributaries, suggesting an out-of-phase relationship (Rains and Welch 1988). All four terraces in tributary valleys formed over approximately the same time span as the youngest

terrace in the North Saskatchewan valley. Factors other than climate change must be considered in order to fully explain these fluvial adjustments.

This study examines the postglacial evolution of some of the main river systems and their tributaries in central and southern Alberta, focusing on the North Saskatchewan and Red Deer River drainage basins. The timing and nature of fluvial adjustments and their possible causes are also considered.

## 2.2 Study Area

The study area (fig.2.1) contains a diversity of physiographic, vegetation and climatic zones (figs.2.2a-2.2c). The regional climate is continental with long, cold winters and short, warm summers. In general, total precipitation decreases east of the foothills, though wetter, upland areas such as the Cypress Hills, with a local relief of >300m, provide a sharp climatic contrast to the adjacent semiarid plains.

Bedrock geology consists of Upper Cretaceous formations (fig.2.2d). These formations are dominated by weakly cemented and compacted sandstone and mudstone and are highly erodible where exposed. Local outcrops of ironstone concretions in the bedrock offer greater resistance to erosion. Along the valley sides of many river systems, postglacial fluvial erosion and mass movements (DeLugt and Campbell 1992) have stripped the surficial deposits and exposed the highly erodible bedrock, forming badlands in some places.

The oldest surficial deposits consist of preglacial gravels and sands deposited by easterly flowing river systems. The Empress Formation (Whitaker and Christiansen 1972), formerly known as Saskatchewan Gravels and Sands (Rutherford 1937;Stalker 1968a), directly overlies bedrock and underlies the oldest glacial deposits. The Empress Formation consists of quartzite and sandstone lithologies

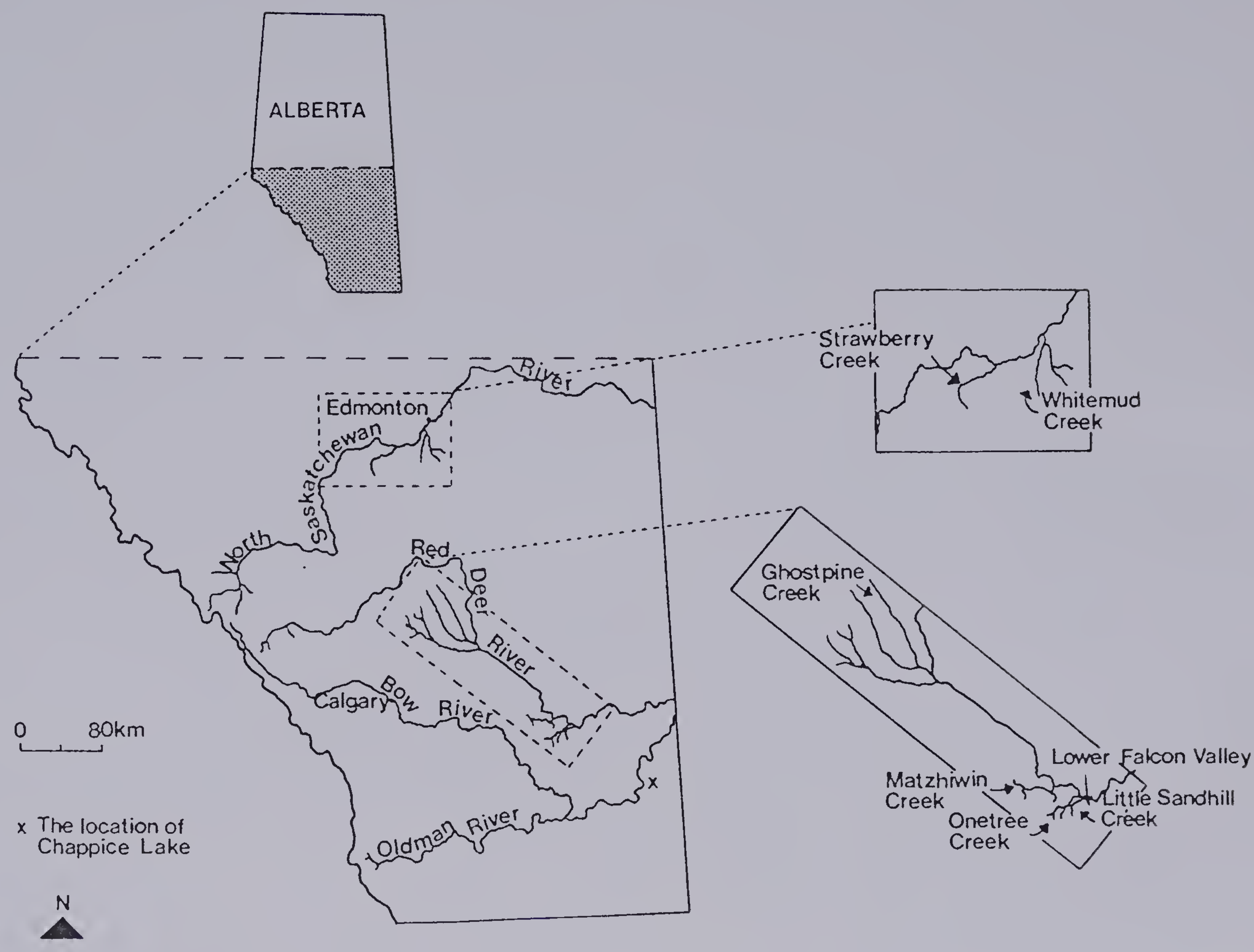



Fig.2.1. The location of the study area and selected creeks and river systems.

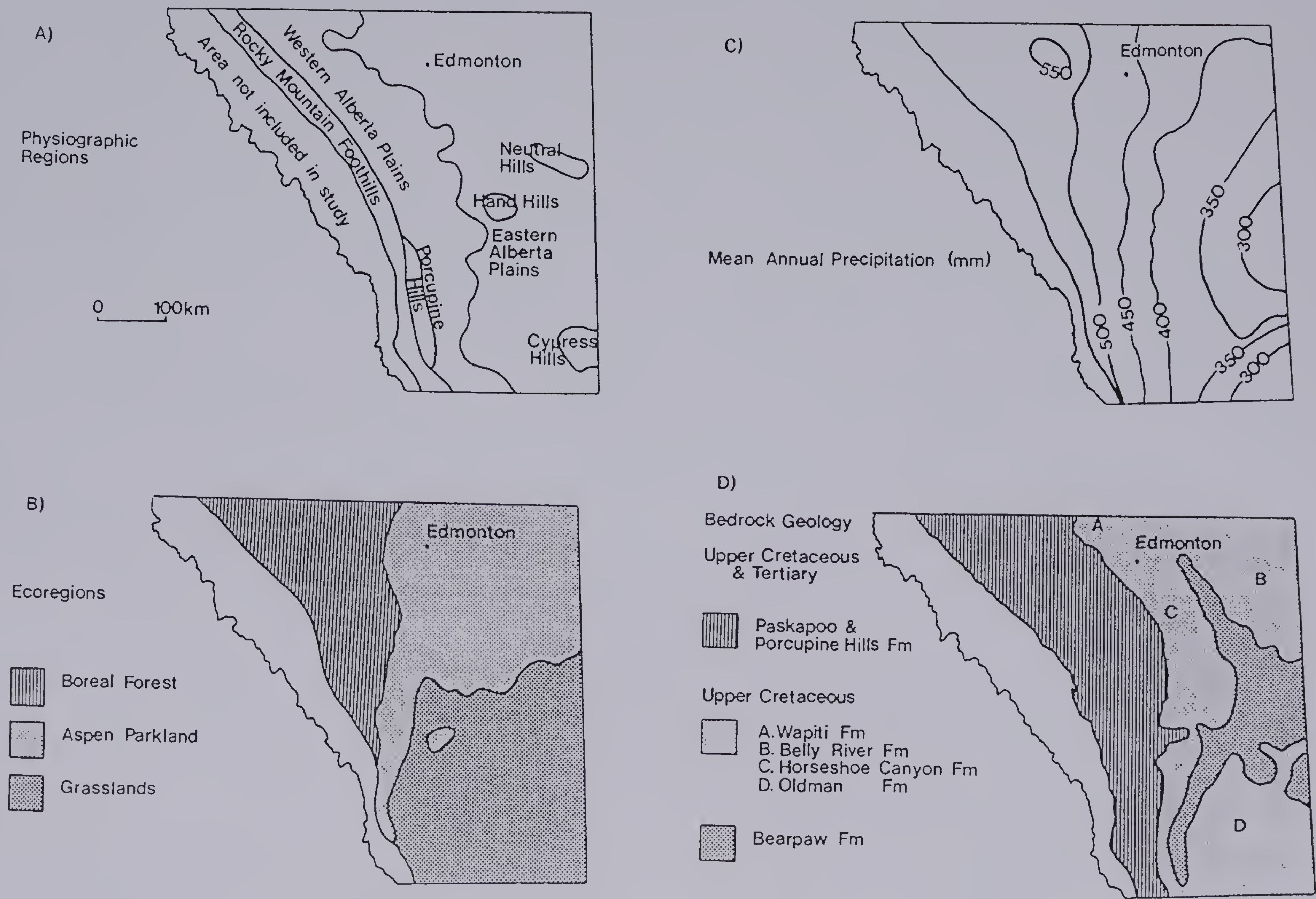



Fig.2.2. The general characteristics of the study area (modified after Atlas of Alberta 1969).

with no Shield material (Christiansen 1992).

Glacially derived sediments were deposited across Alberta during the late Wisconsinan glaciation with locally thick deposits of diamicton filling preglacial valleys. Lacustrine sediments deposited in proglacial lakes during Laurentide ice wasting and retreat to the northeast (St-Onge 1972) overlie the diamicton deposits. Other surficial deposits include various postglacial fluvial and aeolian sediments.

## 2.3 Previous Studies

The locations of the following river systems are revealed on fig.2.1. Rains and Welch (1988) provide a comprehensive review of previous studies concerning terrace stratigraphy and postglacial evolution of the North Saskatchewan River and some of its tributaries.

The postglacial development of the lower Red Deer River valley was considered by MacPherson (1968) and in part by Bryan *et al.*(1987). In both cases, only a broad pattern of the postglacial evolution is available because of scarce datable deposits. Detailed alluvial chronologies for small tributary creeks of the Red Deer River include the lower Falcon valley (O'Hara 1986;O'Hara & Campbell 1993), Little Sandhill Creek (Campbell & Evans 1990), Onetree Creek (Campbell *et al.*1993), Ghostpine Creek (Rains *et al.*1994) and Matzhiwin Creek (this study).

Studies of the valley fill and terrace stratigraphy for the Bow River include: Churcher (1968),Stalker (1968b), Wilson (1974,1981,1983),Wilson & Churcher (1978,1984) and Jackson *et al.*(1982).

## 2.4 The late glacial/early Holocene evolution of large river systems in central and southern Alberta.

The large, easterly flowing rivers in central and southern Alberta began incising their valleys in the late Pleistocene/ early Holocene during Laurentide ice retreat to

the northeast (St-Onge 1972;Christiansen 1979;Dyke & Prest 1987). As Laurentide ice retreated northeastward down the regional topographic slope in Alberta, proglacial lakes formed. These lakes acted as temporary baselevels for the early postglacial, easterly flowing streams (St-Onge 1972). Proglacial lake drainage following ice recession resulted in formation of generally easterly flowing spillway rivers.

During deglaciation in the foothills the early, postglacial river systems were dominantly glaciofluvial in origin and graded to local, proglacial lake levels (St-Onge 1972). Upper terraces of the Bow River near Cochrane, 30km west of Calgary, consist of deltaic deposits built into proglacial lake margins during early deglaciation and a lower set of terraces were later carved into a gravel fill (Stalker 1968b). The lower gravel fill (Bighill Creek Formation) was deposited between 12.0 - 10.0ka BP before being incised by the Bow River (Stalker 1968b). A similar gravel fill downstream near Calgary represents a period of rapid aggradation prior to drainage of Glacial Lake Calgary (Wilson and Churcher 1978).

Incision of major valleys occurred later on in the plains following ice retreat and lake drainage. The ancestral North Saskatchewan River formed in the Edmonton region at ca.12.5ka BP (or later) after the drainage of Glacial Lake Edmonton through the Gwynne outlet (St- Onge 1972). Two bone-derived radiocarbon dates within the upper terrace alluvium (T1) of the North Saskatchewan River in the Edmonton region range from 10.7 - 11.3ka BP (Rains & Welch 1988) and relate to a major period of aggradation possibly associated with a temporary change in baselevel as late phases of Glacial Lake Edmonton evolved (Rains 1990). The lowest terrace (T4) is believed to have begun aggradation around 8.0ka BP on the basis of $^{14}C$ dated samples. Mazama ash dated at about 6.8ka BP (Bacon 1983), occurs higher in the T4 alluvial sequence. This lower terrace remains part of the modern floodplain. The period between the upper and lower

terraces show that the North Saskatchewan River rapidly downcut following deglaciation in response to changing local baselevels interspersed with brief periods of stability and aggradation. Incision rates appear to have slowed around 8.0ka BP, when the lowest terrace began to form (Rains and Welch 1988;Cruden *et al* .1993) (fig.2.3).

MacPherson (1968) reconstructed the Holocene alluvial history for the lower Red Deer River based on interpretation of subsurface stratigraphy. Deep incision by meltwaters in early postglacial times (12 - 14ka BP; Bryan *et al*.1987) was followed by deposition of up to 40m of fine grained alluvium. This aggradational phase may reflect increased sediment supply from the badlands along the margins of the Red Deer River (Bryan *et al*.1987). The river has subsequently trenched this fine grained alluvium, producing a series of terraces. The cause of incision is unknown but it may reflect reduced sediment supply from the badland surfaces following widespread deposition of loess around 5.0ka BP (Bryan *et al*.1987).

Rapid rates of downcutting occurred in both the North Saskatchewan and Red Deer rivers during the early postglacial period. Both drainage systems probably had high discharge regimes during deglaciation and the highly erodible nature of the underlying bedrock, together with probable glacioisostatic uplift, would have enhanced rapid downcutting.

The North Saskatchewan River and the Red Deer River may partly follow ice marginal spillways and, in places, follow preglacial valleys (Stalker 1961). MacPherson (1968) noted a distinctive V-shaped morphology in locations where the Red Deer River has incised into bedrock and a characteristic U-shape in areas where the channel has incised into the thick glacial deposits of the preglacial Bow valley.

The rapid incision rates slowed in the mid-Holocene as discharge declined. Diminishing discharges and a reduced level of fluvial activity appears to be reflected in the

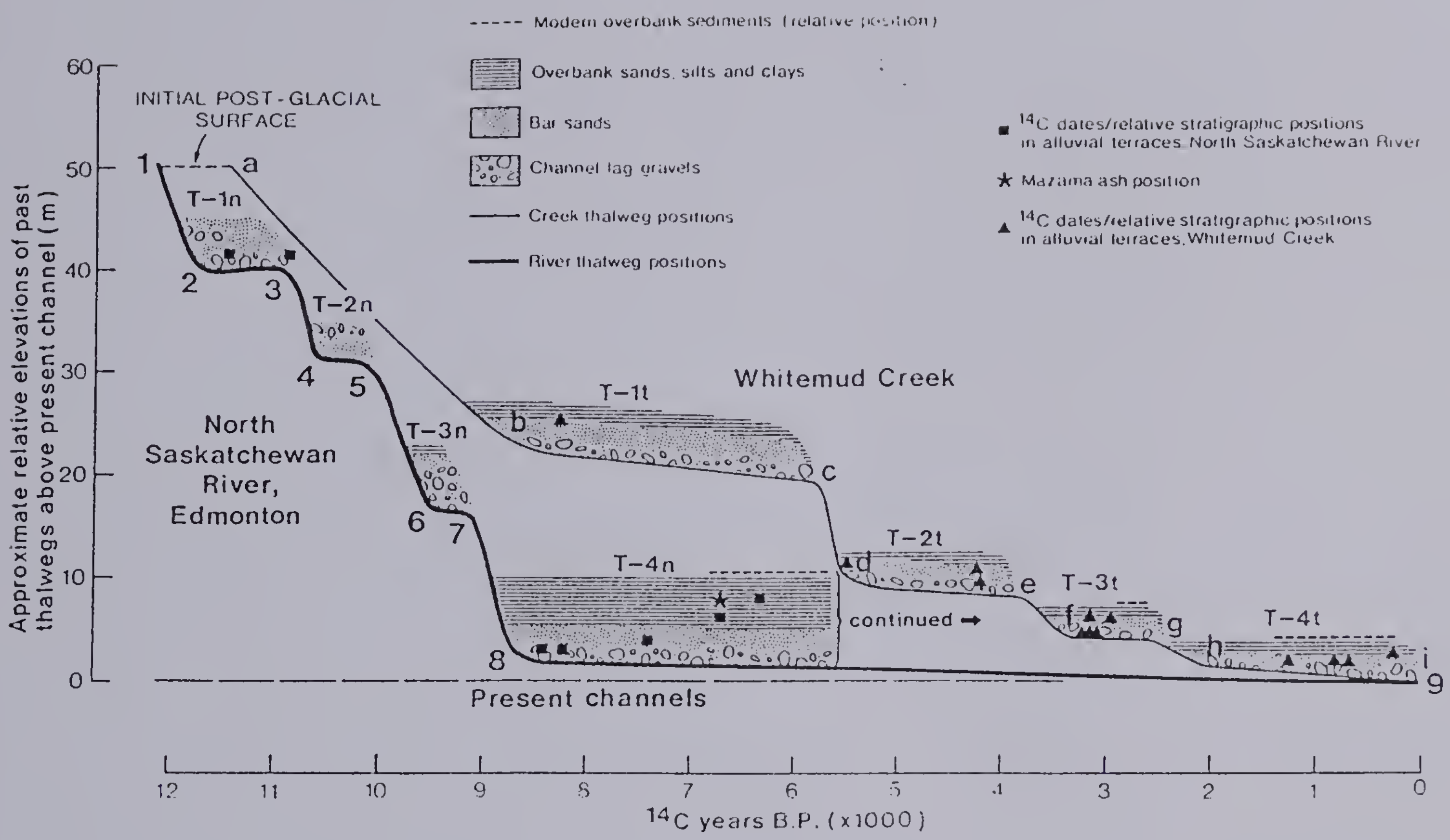



Fig.2.3. Detailed late glacial and postglacial incision curves of the North Saskatchewan River and Whitemud Creek, Edmonton (Cruden et al.1993).

fine grained alluvium of the lower valley fill compared to the upper sand and gravel terraces in the lower Red Deer River (MacPherson 1968).

**2.5 Holocene evolution of tributary creeks**

Smaller tributary creeks in central and southern Alberta contain alluvial terraces in varying degrees of extent, preservation and number. Tributaries formed initially as gully systems or narrow spillways feeding into the main channel, which acted as a local baselevel control. During rapid incision in the trunk streams the tributaries were unable to downcut at the same rate given their smaller discharges reflecting smaller drainage basin size. As a result the tributaries developed steep, convex-up long profiles (Rains & Welch 1988;Donnelly 1990) especially in downstream reaches near the confluence with the trunk stream.

Within the tributary valleys are a variety of discontinuous paired and non-paired alluvial terraces. There are four paired terraces in Whitemud and Strawberry creeks (Rains and Welch 1988), three paired alluvial terraces in Ghostpine Creek (Rains *et al.*1994), three paired alluvial terraces in Matzhiwin Creek (this study) and a variety of paired and non-paired terraces in Onetree Creek (Campbell *et al.*1993) and Little Sandhill Creek (Campbell and Evans 1990). In the upstream reaches of the tributary valleys, terrace remnants typically merge or become indistinct because of the shallow depth of valley incision. Toward the confluence with the main stream the increasing effects of valleyside erosion and the early, deep and rapid incision have either not favoured terrace development or have removed the terraces (Rains *et al.*1994). Rains & Welch (1988) noted the importance of a gravel bed armour in the steeper, downstream reaches of Whitemud Creek. Deep incision supplied large quantities of gravels to the stream from Laurentide till, preglacial gravel, indurated ironstone and

redistributed gravel lags from early, higher level terrace alluvium. Upstream, in the shallower reaches of the valley, the main gravel sources remain below the level of incision and the gravel bed armour disappears. Rains & Welch (1988) suggested that this bed armouring offers greater resistance to channel incision as well as enhancing lateral migration by the stream.

Terrace alluvium generally consists of channel gravels, point bar sands and overbank fines, reflecting the typical fining-up sequence of a meandering stream. Similar characteristics between upper and lower terrace alluvium in Whitemud and Strawberry creeks suggest that they have maintained meander-form channels throughout most, if not all of their postglacial evolution (Rains and Welch 1988).

Net degradation occurred in both tributary and trunk streams during the postglacial period, interspersed with phases of aggradation and stability. Table 2.1 lists the radiocarbon dates related to terrace sequences in the study area. Interpretation of the $^{14}C$ dates reveals overlapping periods of aggradation. Radiocarbon dates indicate that the highest terrace (T1) in Whitemud Creek began aggradation around 8.0ka BP. Dates ranging between 7.6 - 7.1ka BP have been obtained from bones in upper (T1) terrace alluvium in Ghostpine Creek and Little Sandhill Creek (table 2.1). These radiocarbon dates, and the presence of Mazama ash in upper terrace alluvium in Strawberry Creek (Rains & Welch 1988), suggest widespread channel aggradation occurred around 8.0ka BP up until at least 6.8ka BP. Dates from lower terrace alluvium in Whitemud, Onetree, Matzhiwin and Ghostpine creeks reveal widespread channel aggradation between 3.2 - 2.0ka BP and 1.8 - 0.3ka BP (table 2.1).

In summary, these tributary creeks have all developed steep, convex-up profiles in response to rapid, local baselevel lowering in trunk streams. Although net degradation has occurred throughout the Holocene there have been various episodes of stability and floodplain formation.

Table 2.1. Radiocarbon dates retrieved from terrace alluvium in the study area. The stratigraphic position ranges from T1 (oldest terrace) to T4 (youngest terrace).

| Terrace | Radiocarbon date (BP) | Laboratory number | River | Reference |
|---|---|---|---|---|
| T1 | 11 345+/- 420 | S-2385 | N.Saskatchewan | Rains & Welch (1988) |
| T1 | 10 740+/- 470 | S-1923 | N.Saskatchewan | Rains & Welch (1988) |
| T4 | 6 955 +/- 80 | S-1706 | N.Saskatchewan | Rains & Welch (1988) |
| T1 | 8 195+/-1090 | S-1798 | Whitemud Creek | Rains & Welch (1988) |
| T2 | 5 490 +/- 230 | S-2387 | Whitemud Creek | Rains & Welch (1988) |
| T2 | 4 255 +/- 150 | S-1797 | Whitemud Creek | Rains & Welch (1988) |
| T2 | 4 220 +/- 250 | S-2392 | Whitemud Creek | Rains & Welch (1988) |
| T3 | 3 255 +/- 90 | S-1795 | Whitemud Creek | Rains & Welch (1988) |
| T3 | 3 200 +/- 80 | S-1794 | Whitemud Creek | Rains & Welch (1988) |
| T3 | 3 200 +/-125 | S-2389 | Whitemud Creek | Rains & Welch (1988) |
| T3 | 3 180 +/- 85 | S-1796 | Whitemud Creek | Rains & Welch (1988) |
| T3 | 2 940 +/- 125 | S-2388 | Whitemud Creek | Rains & Welch (1988) |
| T3 | 2 025 +/- 205 | S-2390 | Whitemud Creek | Rains & Welch (1988) |
| T4 | 1 220 +/- 70 | S-1793 | Whitemud Creek | Rains & Welch (1988) |
| T4 | 810 +/- 75 | S-1790 | Whitemud Creek | Rains & Welch (1988) |
| T4 | 705 +/- 70 | S-1791 | Whitemud Creek | Rains & Welch (1988) |
| T4 | 315 +/- 70 | S-1792 | Whitemud Creek | Rains & Welch (1988) |
| T2? | 2 880 +/- 110 | AECV1276c | Onetree Creek | Campbell *et al.* (1993) |
| T2? | 2 330 +/- 100 | AECV 906c | Onetree Creek | Campbell *et al.* (1993) |
| T2? | 2 080 +/- 100 | AECV 905c | Onetree Creek | Campbell *et al.* (1993) |
| T2? | 2 860 +/- 90 | AECV 904c | Onetree Creek | Campbell *et al.* (1993) |
| T2? | 2 590 +/- 90 | AECV 911c | Onetree Creek | Campbell *et al.* (1993) |
| T3? | 1 230 +/- 80 | AECV 912c | Onetree Creek | Campbell *et al.* (1993) |
| T3? | 1 310 +/- 80 | AECV 80 | Onetree Creek | Campbell *et al.* (1993) |
| T1 | 7 610 +/- 70 | TO 1829 | Ghostpine Creek | Rains *et al.*(1994) |
| T2 | 2 580 +/- 90 | AECV 9440 | Ghostpine Creek | Rains *et al.*(1994) |
| T3 | 1 320 +/- 90 | TO 4576 | Matzhiwin Creek | This study |
| T3 | 1 860 +/- 70 | TO 4577 | Matzhiwin Creek | This study |
| T1? | 7 150 +/- 150 | AECV 605c | Little Sandhill Creek | Campbell & Evans (1990) |
| T2/3? | 1 520 +/- 90 | AECV 604c | Little Sandhill Creek | Campbell & Evans (1990) |

Given the sparse dating control it is difficult to construct accurate incision curves and compare alluvial histories of tributary creeks. In some cases tributary creeks developed out-of-phase with trunk rivers, though on the basis of available dates the tributary creeks appear to show some degree of large-scale regional correlation with each other, especially in the mid to late Holocene. Table 2.2 summarises the postglacial evolution of the North Saskatchewan and Red Deer rivers and tributary creeks in the study area.

**2.6 Causes of fluvial adjustment**

Long term fluvial adjustments have been explained by a variety of factors, primarily through a change in an external variable such as baselevel, landuse, climate or isostasy. However, Schumm (1973) noted that within a region, different parts of the landscape behaved differently to the last external influence, some not responding at all. He attributed this to the complex response of geomorphic systems. Schumm (1973) recognised two types of thresholds; extrinsic thresholds which are exceeded by changes in an external variable such as climate or baselevel; intrinsic thresholds which are exceeded without a change in an external variable and result in a change in the system. Threshold theory has been used to explain complex alluvial histories in areas where sediment yields are high and cut and fill cycles are a natural sequence by which the mechanism controlling the way sediment is transported out of the system is unrelated to changes in an external variable.

Despite the recognition of the many factors which influence stream behaviour, past research has often focused on climate as the primary influence (Brakenridge 1980;Knox 1983). However, there is no generally accepted model to explain the way in which fluvial processes respond to climatic change. There are two reasons for this: First, there is incomplete understanding of the processes that determine stream behaviour and the ways in which climate

Table 2.2. General postglacial evolution of the North Saskatchewan River, near Edmonton, the lower Red Deer River and selected creeks.

| Years BP x 1000 | North Saskatchewan River. (Edmonton region) | Whitemud Creek | Red Deer River (Dinosaur Provincial Park) | Ghostpine Creek | Lower Falcon valley | Little Sandhill Creek | Onetree Creek | Matzhiwin Creek |
|---|---|---|---|---|---|---|---|---|
| 15 | | | | | | | | |
| | | | Spillway incision | | | | | |
| 14 | | | | | | | | |
| | | | Broad valley incision | Glacial Lake Drumheller drains. | | | | |
| 13 | Drainage of Glacial Lake Edmonton (St-Onge 1972) | | | | Intial incision of valley | Initial incision of valley | Initial incision of valley | Initial incision of valley |
| | | | Deep incision of valley | Initial incision of valley | | | | |
| 12 | Initial incision of valley | Initial incision of valley | | | | | | |
| 11 | T1 aggradation | | | | Deposition of sand and gravel fill | | | |
| 10 | T2 / T3 agrradation Incision | | Aggradation of fine grained alluvium | | | | | |
| 9 | | | | | | Ponds form on prairie surface until after 7.0ka BP | | |
| | T4 aggradation still active floodplain today | | | | | | | |
| 8 | | T1 aggradation | | | | | | |
| | | | | T1 aggradation | Deposition of alluvial fan material on valley floor | | | Deposition of alluvial fan material on valley floor |
| 7 | | Incision | | | | | | |
| 6 | | | | Incision | | | | |
| | | T2 aggradation Incision | Aeolian activity | | | | | |
| 5 | | | | | | | | |
| 4 | | | incision of fine grained alluvium | | Incision | Incision | | Incision |
| 3 | | T3 aggradation | | | | | Aggradation | |
| | | | | T2 aggradation Incision | | | | |
| 2 | | Incision | | | | | Incision | |
| | | | | | | Aggradation of lower terrace | | T3 aggradation |
| 1 | | T4 aggradation Incision | | T3 aggradation Incision | Aggradation Incision | Incision | Aggradation Incision | Incision |
| Pcsent | | | | | | | | |

Sources: MacPherson (1968), Bryan *et al.*(1987), Rains and Welch (1988), Campbell and Evans (1990), Campbell *et al.*(1993), O'Hara and Campbell (1993) and Rains *et al.*(1994).

change effects these processes. Second, detailed, dated palaeoclimate reconstructions are often based on lake cores; indirect indicators of fluvial processes.

The effects of climatic controls on stream behaviour involves consideration of the magnitude and frequency of geomorphic processes (Wolman & Miller 1960). In some environments low magnitude, high frequency events are considered of primary importance in shaping the landscape. Wolman and Leopold (1957) noted that 80-90% of typical floodplain deposits consist of sediments from low magnitude/ high frequency discharges fostering lateral accretion processes. Climatic shifts result in vegetation, runoff and sediment yield changes and a gradual adjustment of channel dimensions to the new regime.

In other environments, extremely high magnitude/ low frequency events are considered of greatest geomorphic importance (in terms of shaping the landscape). These catastrophic events leave a long term imprint on the landscape. Such events result in rapid rates of erosion and or deposition, perhaps followed by relatively long periods of stability. Schumm and Lichty (1963) noted the dominance of overbank sediments in floodplain construction deposited during flood events. During high magnitude events both channel widening and incision can occur as well as floodplain construction through the deposition of overbank sediments. Stene (1980) observed that terraces along streams within the Porcupine Hills region, Alberta, consist largely of overbank sediments deposited during relatively high magnitude storms.

Wolman and Gerson (1978) suggested that in order to assess the importance of high magnitude events on the landscape, the processes which occur between such events must also be considered. In a semiarid fluvial system, a high magnitude/ low frequency event may result in irreparable morphological change due to the inability of intervening flows to transport large amounts of sediment and

minimal stabilising bank vegetation. In such an environment recovery rates are extremely slow. However, evidence of morphological change from the same event in more humid environments may last only a short period of time due to rapid recovery rates.

In small watersheds drained by ephemeral streams high intensity low duration convectional storms may be of major geomorphic importance (Brakenridge 1980). Because of their limited size such storms will have a minimal effect on a larger drainage system. Therefore, climatic controls on stream behaviour largely depend on the geomorphic characteristics of the basin, the magnitude and frequency of storm events and recovery rates in that basin, related to precipitation, vegetation and sediment yields.

Where there is a lack of detailed palaeoclimate data the task of attributing specific phases of fluvial adjustment to climate change is speculative. Most palaeoclimatic records can only indicate general trends in precipitation and temperature. The majority of palaeoclimatic records are based on pollen reconstructions of past vegetation and are rarely sensitive enough to detect short-lived climatic changes. Palaeoclimate reconstructions based on lake cores may suffer from inadequate dating control or even the problem of contamination of radiocarbon dates from so called "dead carbon" (MacDonald 1989). Given the lack of understanding on the precise effects of the various controls on stream behaviour, and the restricted nature of detailed palaeoclimate records, deciphering the exact cause of fluvial adjustments is difficult.

## 2.7 The influence of climate and baselevel changes on fluvial systems in central and southern Alberta

The extent to which the northern Great Plains experienced mid-Holocene aridity or whether warm/ arid conditions occurred in the early Holocene remain unresolved problems

(Barnosky 1989). Dates that have been proposed for the end of the Hypsithermal in central and southern Alberta range from ca.7.0 - 4.0ka BP (Vance *et al.* 1983,1992;Schweger & Hickman 1989;MacDonald 1989;Sauchyn 1990), prior to modern vegetation and climate patterns being established. Similar trends have been documented in Montana where warm/arid conditions are interpreted as occurring around 9.4 - 6.0ka BP (Barnosky 1989).

A study of water level fluctuations at Chappice Lake in southern Alberta (fig.2.1), using Ruppia abundance as a proxy for lake levels (Vance *et al.*1992), has revealed climatic variations after 4.0ka BP. They interpreted lake level variations as reflecting the Neoboreal (2.6 - 1.0ka BP), the Medieval Warm Phase (1.0 - 0.6ka BP), the Little Ice Age (0.6 -0.1Ka BP) and recent historical droughts. The Chappice Lake interpretation may not reflect the timing or nature of climate change which occurred in the more northerly parts of the study area.

In order to assess the impact of climatic variations on stream behaviour in the study area, radiocarbon dates retrieved from terrace deposits (table 2.1) are plotted with elevation shown as a percentage above channel compared to total valley depth at that location (fig.2.4). The climate curve for Chappice Lake, as interpreted by Vance *et al.*(1992), is displayed below the radiocarbon dates. Each $^{14}C$ date is a sample within the terrace aggradational phase. Generalised clusters appear between 3.2 - 2.0ka BP and 1.8 - 0.3ka BP. A period of widespread incision around 2.0ka BP in both Onetree Creek and Whitemud Creek (fig.2.4) corresponds to the Neoboreal period. A further period of widespread incision occurred between 0.8-0.3ka BP resulting in abandonment of the lowest terrace surface in Onetree, Matzhiwin and Whitemud creeks and corresponds to the Little Ice Age (fig.2.4). These phases of regional incision reveal partial synchronicity with periods of rising lake levels in Chappice Lake (Vance *et al.*1992). There also appears to be

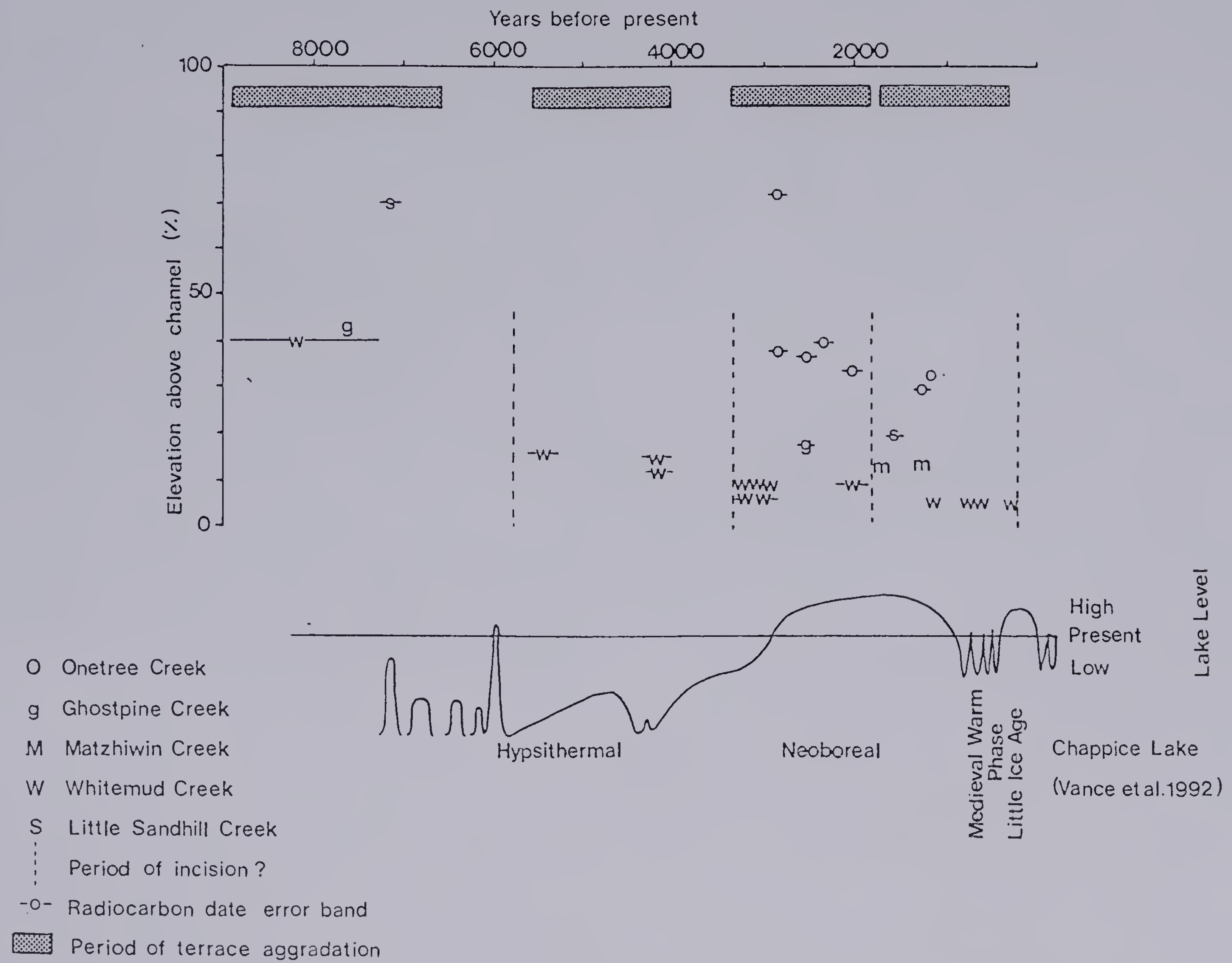
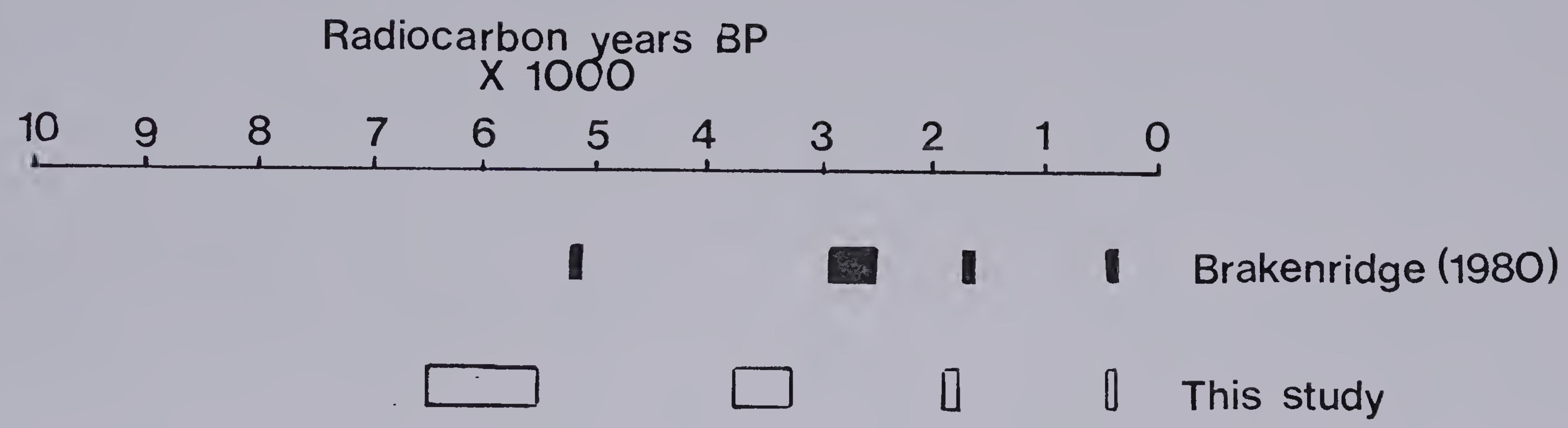



Fig.2.4. Radiocarbon dates retrieved from alluvial terrace deposits from selected creeks within the study area (fig.2.1). Each $^{14}C$ date represents part of a terrace aggradational phase (Rains and Welch 1988;Campbell and Evans 1990; Campbell *et al.*1993; Rains *et al.*1994). Stratigraphic position is shown as a percentage above channel compared to total valley depth at that site.

some relationship between stream channel aggradational phases and low lake levels; 8.0 - 6.8ka BP, 5.5 - 4.0ka BP (possible Hypsithermal) and 1.8 - 0.3ka BP (Medieval Warm Phase). However, the major phase of aggradation between 3.0 - 2.0ka BP corresponds to a period of rising lake levels. By contrast, however, a palaeoclimate reconstruction from Waldsea Lake in south-central Saskatchewan, documents a brief period of warm/arid conditions at this time (2.8 - 2.0ka BP) when shallow mudflat conditions prevailed (Last & Slezak 1988).

The geographically dispersed palaeoenvironmental data, and incomplete alluvial histories, make it difficult to determine whether long term fluvial adjustments during the Holocene occurred as a result of climate change within the study area. From fig.2.4 it is tempting to suggest such a relationship with incision occurring during brief, cool/moist periods and aggradational phases prevailing between such intervals, possibly when there is a trend toward warm/arid conditions. Even if such a relationship exists, it is still unclear exactly how climate change effects stream behaviour. It may either occur directly through precipitation or possibly indirectly through the vegetation cover, influencing runoff and sediment yields (Knox 1983).

Comparison of phases of incision from this study with similar data collected from both western U.S.A and central European streams and rivers (see Brakenridge 1980) reveals some degree of relationship (fig.2.5). Two major incision phases occurred in the late Holocene (0.4 - 0.3ka BP and 1.9 - 1.8ka BP) in the study area and these correspond well with dates obtained by Brakenridge (1980). However, two earlier incision phases in central and southern Alberta do not correlate so well (fig.2.5). Brakenridge (1980) suggested that episodes of widespread stream erosion occurred during the Holocene and that such episodes coincided with phases of glacier advances, times of decreasing temperature and




Periods of widespread channel incision observed in selected U.S.A and central European streams and rivers by Brakenridge (1980).

Periods of widespread channel incision observed in selected creeks in the study area (Rains and Welch 1988;Campbell and Evans 1990;Campbell *et al.*1993;Rains *et al.*1994).

Fig.2.5. Phases of widespread Holocene stream incision in western U.S.A and central European Rivers (see Brakenridge 1980) and this study.

increasing precipitation (LaMarche 1978). Radiocarbon dating control for Holocene glacier fluctuations is limited in North America, though the period of incision which occurred between ca.0.8 - 0.3ka BP corresponds with the well documented Little Ice Age advance (Luckman and Osborn 1977;Gardner & Jones 1985). Little is known about possible glacial advances prior to this event. Gardner and Jones (1985) presented evidence based on two radiocarbon dates for a glacial advance at about 4.0ka BP in Boundary Glacier, Banff National Park. The incision phase (noted on fig.2.4) that occurred around 4.0 - 3.5ka BP in the study area corresponds with this glacial advance, perhaps supporting the hypothesis that phases of widespread stream incision occur during cool/moist periods.

Cyclic changes in upper atmospheric circulation and intensified meridionality possibly result in cool/moist phases (Brakenridge 1980). It has been suggested by Leopold *et al.*(1964) that river channels in some environments are formed by floods with a recurrence interval of 1-2 years. Phases of channel widening and incision may result when floods of such recurrence increase in magnitude, resulting from changes in upper atmosphere circulation patterns (Brakenridge 1980;Knox 1983). If the above assumptions are correct and brief periods of incision are associated with changes in that circulation, and changes in flood magnitude/frequency, then it appears to be only applicable to small tributary creeks in the study area and not to the larger river systems. The fact that there is little change evident in the North Saskatchewan River during the past 8000 years indicates the importance of drainage basin size. Localised, high intensity, convectional storms may have a major impact on the hydrology of a small tributary basin, but will have a minimal effect on larger drainage basins. However, the unique characteristics of each drainage basin will determine the exact response to a specific climate change and the lag time involved.

The late Holocene pattern of two incision phases for streams in the study area (Rains and Welch 1988;Campbell *et al*.1993;Rains *et al*.1994) and from data collected by Brakenridge (1980) may be interpreted as representing episodes of widespread channel erosion, possibly a result of regional climate change. However, earlier episodes do not appear to be so well defined. Incision phases in the study area around 4.0 - 3.5ka BP and 6.5 - 5.6ka BP, predate those of Brakenridge (1980) by 2-3 centuries, although a similar number of episodes is noted in both studies. These disparaties may indicate the effect of local influences on stream behaviour other than climate. For example, beaver dam construction and bed armouring both affected stream behaviour in Whitemud Creek (Rains 1987;Rains and Welch 1988).

In summary, climate change may be a primary forcing function governing the broad patterns of channel behaviour but many other factors are involved. Rapid incision in the late glacial/ early Holocene of both tributary streams and trunk rivers in the study area was probably more a function of isostatic rebound and baselevel changes rather than climate. As glacially-related discharge and isostatic variables declined in importance towards the mid-Holocene, it is probable that the dominance of climatically-controlled variables prevailed in smaller, tributary basins, resulting in several phases of channel aggradation and degradation. Although net erosion has occurred throughout the Holocene in these fluvial systems, it appears from the valley morphologies that relatively long periods of aggradation were followed by brief episodes of incision. Alluvial chronologies reviewed by Knox (1983) support the concept that stream aggradation may be a long-term, slow process whilst incision episodes begin abruptly and last for a shorter duration. Phases of long term stability and floodplain construction, followed by brief episodes of erosion are well illustrated on the incision curve for

Whitemud Creek (fig.2.3).

## 2.8 Conclusion

During the late glacial retreat of Laurentide ice, baselevel changes controlled by regressive offlap of proglacial, ice-dammed lakes promoted incision of the large easterly flowing rivers in central and southern Alberta. Brief periods of stability and aggradation occurred as a result of fluctuations in Laurentide ice front positions and proglacial lakes. Rapid rates of incision by such rivers may also be partially related to the effects of glacioisostatic rebound. In the Edmonton region the lowest alluvial terrace in the North Saskatchewan River has been the active floodplain for about the past 8000 years.

Creek systems in the study area have developed distinctive convex-up profiles in response to the rapid incision rates by the trunk rivers. Terrace preservation has not been favoured in downstream reaches especially near the confluence with the trunk streams. However, upstream reaches in numerous creeks contain evidence of several cut and fill cycles. Radiocarbon dates retrieved from deposits in terrace alluvium suggest general, synchronous phases of aggradation and degradation in these systems which partially correspond to incision phases noted by Brakenridge (1980). These incision phases appear to coincide with brief cool/moist conditions. Intensified meridionality in the upper atmospheric circulation may produce such climatic shifts and influence the magnitude and frequency of storm events capable of significant channel widening and incision. However, within the study area only small, tributary basins appear to be sensitive to those climatic fluctuations.

Although net degradation has occurred during the Holocene, it appears that episodic erosion is rapid and short-lived, followed by relatively long phases of stability and slow deposition. High magnitude events seem of importance in terms of influencing long term stream

behaviour and morphology. Although climate may have been the dominant influence on stream behaviour during the mid to late Holocene in the small, tributary creeks in central and southern Alberta, local and regional baselevel changes (and isostatic rebound) were initially important controls.

The many controls on stream behaviour are not well understood though widespread phases of incision have been recognised in central and southern Alberta and from studies outside the study area. The regional evidence suggests the importance of global climate change on stream behaviour, even if the processes remain unclear. However, attributing all cut and fill cycles to climate change is almost certainly an over-simplification, and the numerous other controls on stream behaviour should be evaluated.

## 2.9 Bibliography


Atlas of Alberta. 1969. University of Alberta Press in association with University of Toronto Press.

Bacon, C.R. 1983. Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A. Journal of Volcanology and Geothermal Research, **18**: 57-115.

Barnosky, C.W. 1989. Postglacial vegetation and climate in the northwestern Great Plains of Montana. Quaternary Research, **31**: 57-73.

Brakenridge, G.R. 1980. Widespread episodes of stream erosion during the Holocene and their climatic cause. Nature, **283**: 655-656.

Bryan, R.B,Campbell, I.A. and Yair, A. 1987. Postglacial geomorphic development of the Dinosaur Provincial Park badlands, Alberta. Canadian Journal of Earth Sciences, **24**: 135-146.

Campbell, I.A. and Evans, J.A. 1990. Glaciotectonism and landsliding in Little Sandhill Creek, Alberta. Geomorphology, **4**: 19-36.

Campbell, I.A, Rains, R.B, Shaw, J. and Evans, J.A. 1993. Glacial and Holocene Geomorphology of the Alberta Prairies. A Field Guide for the Third International Geomorphology Conference, Hamilton, Ontario.

Christiansen, E.A. 1992. Pleistocene stratigraphy of the Saskatoon area, Saskatchewan, Canada: An update. Canadian Journal of Earth Sciences, **29**: 1767-1778.

Christiansen,E.A. 1979. The Wisconsin deglaciation of southern Saskatchewan and adjacent areas. Canadian Journal of Earth Sciences, **16**: 913-938.

Churcher,C.S. 1968. Pleistocene ungulates from the Bow River gravels at Cochrane, Alberta. Canadian Journal of Earth Sciences, **5**: 1467-1488.

Cruden, D.M, Rains, R.B. and Thomson, S. 1993. A short walk in the North Saskatchewan River Valley. Field Trip Guidebook, Geological Association of Canada/ Mineralogical Association of Canada, Edmonton, Alberta.

Delugt, J. and Campbell, I.A. 1992. Mass movements in the badlands of Dinosaur Provincial Park, Alberta, Canada. Catena Supplement **23**: 75-100.

Donnelly, L.M. 1990. A study of longitudinal profiles of tributaries of the North Saskatchewan River. B.Sc (Honours) thesis, University of Alberta, Edmonton, Alberta.

Dyke, A.S. and Prest, V.K. 1987: Late Wisconsin and Holocene history of the Laurentide ice sheet. Geographie physique et Quaternaire, **LXI**: 237-263.

Gardner, J.S. and Jones, N.K. 1985. The Neoglacial Advance of Boundary Glacier, Banff National Park, Alberta. Canadian Journal of Earth Sciences, **22**: 1753-1755.

Jackson, L.E, MacDonald,G.M. and Wilson,M.C. 1982. Paraglacial origin for terraced river sediments in Bow Valley, Alberta. Canadian Journal of Earth Sciences, **19**: 2219-2231.

Knox, J.C. 1983. Responses of river systems to Holocene climates. In Late Quaternary Environments of the U.S.A. Edited by W.E Wright, University of Minnesota Press, Minneapolis: 26-41.

LaMarche, V.C. 1978. Tree-ring evidence of past climatic variability. Nature, **276**: 334-338.

Last, W.M. and Slezak, L.A. 1988. The salt lakes of western Canada: A palaeolimnological overview. Hydrobiologia, **158**: 301-316.

Leopold, L.B, Wolman, M.G. and Miller, J.P. 1964. Fluvial Processes in Geomorphology. San Francisco, Freeman.

Luckman, B.H and Osborn, G.D. 1977. Holocene glacier fluctuations in the middle Canadian Rocky Mountains. Quaternary Research, **11**: 52-77.

MacDonald, G.M. 1989. Postglacial palaeoecology of the forest- grassland ecotone of southern Alberta: New insight on vegetation and climate change in the Canadian Rocky Mountains and Adjacent foothills. Palaeogeography, palaeoclimatology, palaeoecology, **73**: 155-173.

McDowell, P.F. 1983. Evidence of stream response to Holocene climatic change in a small Wisconsin watershed. Quaternary Research, **19**: 100-116.

MacPherson, H.J. 1968. Historical development of the lower Red Deer Valley, Alberta. The Canadian Geographer, **12**: 227-240.

O'Hara, S.L. 1986. Postglacial geomorphic evolution and alluvial chronology of a valley in the Dinosaur Badlands, Alberta. M.sc. thesis, University of Alberta.

O'Hara, S.L. and Campbell, I.A. 1993. Holocene geomorphology and stratigraphy of the lower Falcon Valley, Dinosaur Provincial Park, Alberta, Canada. Canadian Journal of Earth Sciences, **30**: 1846-1852.

Rains, R.B. 1987. Holocene alluvial sediments and a radiocarbon-dated relict beaverdam, Whitemud Creek, Edmonton, Alberta. Canadian Geographer, **31** (3): 272-277.

Rains, R.B. and Welch, J.E. 1988. Out-of-phase Holocene terraces in part of the North Saskatchewan River basin, Alberta. Canadian Journal of Earth Sciences, **25**: 454-464.

Rains, R.B. 1990. Quaternary geomorphology, North Saskatchewan River basin. Canadian Association of Geographers Field Trip Guide No.1, Edmonton, Alberta.

Rains, R.B, Burns, J.A. and Young, R.R. 1994. Postglacial alluvial terraces and an incorporated bison skeleton, Ghostpine Creek, southern Alberta. Canadian Journal of Earth Sciences, **31**: 1501-1509.

Rutherford, R. 1937.Saskatchewan gravels and sands in central Alberta. Royal Society of Canada Transactions, IV: Series 3, **31**: 81-95.

Sauchyn, D.J. 1990. A reconstruction of Holocene geomorphology and climate, western Cypress hills, Alberta and Saskatchewan. Canadian Journal of Earth Sciences, **27**: 1504-1510.

Schumm, S.A. 1973. Geomorphic thresholds and complex response of drainage systems. In Fluvial Geomorphology. Edited by M.Morisawa. State University of New York, pp. 299-310.

Schumm, S.A. and Lichty, R.W. 1963. Channel widening and floodplain construction along the Cimarron River in southwestern Kansas. U.S Geological Survey Professional Paper, **352-D**: 71-88.

Schumm, S.A. and Lichty, R.W. 1965. Time, space and causality in geomorphology. American Journal of Science, **263**: 110-119.

Schweger, C.E and Hickman, M. 1989. Holocene palaeohydrology of central Alberta: Testing the general circulation-model climate simulations. Canadian Journal of Earth Sciences, **26**: 1826-1833.

Stalker, A.MacS. 1968a. Identification of Saskatchewan gravels and sands. Canadian Journal of Earth Sciences, **5**: 155-163.

Stalker, A.MacS. 1968b. Geology of the terraces at Cochrane, Alberta. Canadian Journal of Earth Sciences, **5**: 1455-1466.

Stalker, A.MacS. 1961. Buried valleys in central and southern Alberta. Geological Survey of Canada, Paper 60-32.

Stene, L.P. 1980. Observations on lateral and overbank deposition- evidence from Holocene terraces, southwestern Alberta. Geology, **8**: 314-317.

St-Onge, D.A. 1972. Sequence of glacial lakes in north-central Alberta. Geological Survey of Canada, Bulletin 213.

Vance, R.E, Mathewes, R.W. and Clague, J.J. 1992. 7,000 year record of lake-level change on the northern Great Plains: A high resolution proxy of past climate. Geology, **20**: 879-882.

Vance, R.E, Emerson, D. and Habgood, T. 1983. A mid-Holocene record of vegetative change in central Alberta. Canadian Journal of Earth Sciences, **20**: 364-376.

Whitaker, S.H. and Christiansen, E.A. 1972. The Empress Group in southern Saskatchewan. Canadian Journal of Earth Sciences, **9**:353-360.

Wilson, M. 1974. Fossil bison and artifacts from the Mona Lisa site, Calgary, Alberta. Plains Anthropologist, **19**: 34-45.

Wilson, M. 1981. Bow River Holocene alluvial chronology at Calgary, Alberta. Geological Association of Canada, Program with Abstracts, **6**: 62.

Wilson, M. 1983. Once upon a river: Archaeology and geology of the Bow River Valley at Calgary, Alberta, Canada. National Museum of Man, Archaeological Survey of Canada, Mercury series, Paper 114.

Wilson, M. and Churcher, C.S. 1978: Late Pleistocene Camelops from the Galleli pit, Calgary, Alberta: Morphology and geologic setting. Canadian Journal of Earth Sciences, **15**: 729-740.

Wilson, M. and Churcher, C.S. 1984. The Late Pleistocene Bighill Creek Formation and its equivelents in Alberta: Correlative potential and vertebrate palaeofauna. <u>In</u> Correlation of Quaternary Chronologies. <u>Edited by</u> W.C Mahaney. Geo Books, Norwich, UK, pp. 159-175.

Wolman, M.G. and Gerson, R. 1978. Relative scales of time and effectiveness of climate in watershed geomorphology. Earth Surface Processes and Landforms, **3**: 189-208.

Wolman, M.G. and Leopold, L.B. 1957. River floodplains: Some observations on their formation. U.S Geological Survey Professional Paper, **282-c**: 87-109.

Wolman, M.G. and Miller, J.P. 1960. Magnitude and frequency of forces in geomorphic processes. Journal of Geology, **68**: 54-74.

## 3.0 The geomorphology and postglacial evolution of Matzhiwin Creek, a small tributary of the Red Deer River, southern Alberta.

### 3.1 Introduction

Studies of stream terrace stratigraphy and alluvial deposits in southern Alberta have provided information on the timing and nature of fluvial adjustments in the area since deglaciation (MacPherson 1968;Bryan *et al*.1987;Campbell and Evans 1990;Evans 1991;Evans and Campbell 1992;O'Hara and Campbell 1993;Rains *et al*.1994). The external variables which are potentially responsible for postglacial stream adjustments include changes in baselevel, effects of tectonism, glacioisostasy, landuse and climate change. The magnitude and timing of stream channel responses to changes in these external variables may also be dependent on internal, geomorphic thresholds within the system. Schumm (1973) and Patton and Schumm (1975) suggested that temporal and spatial patterns of aggradation, degradation and stability may vary within and between fluvial systems due in part to intrinsic, complex geomorphic responses.

Rains and Welch (1988) detected an out-of-phase relationship between the terraces of the North Saskatchewan River near Edmonton, Alberta and some of its tributaries. All four terraces in tributary valleys formed over approximately the same time span as the youngest terrace in the North Saskatchewan River. However, $^{14}C$ dates obtained from bones in terrace deposits of several creek systems in central and southern Alberta are interpreted as representing periods of widespread aggradation and incision. Two major periods of terrace aggradation occurred between ca.3.0 - 2.0 ka BP and ca.1.8 - 0.4 ka BP, separated by brief episodes of incision (Rains and Welch 1988;Campbell and Evans 1990;Campbell *et al*.1993;Rains *et al*.1994). Widespread episodes of stream aggradation and incision suggest the influence of at least one external variable on stream

behaviour, possibly a large-scale climate change. Because the influence of climatic changes on stream behaviour are hard to predict and are not fully understood, correlating specific stream adjustments to climate change is difficult. Furthermore, detailed palaeoclimate reconstructions are geographically dispersed in the area and there are few reliably dated terrace remnants.

In this paper, the alluvial stratigraphy is described and interpreted, and a chronology of events is proposed, for Matzhiwin Creek, a small tributary of the Red Deer River in southern Alberta (figs.3.1 & 3.2). Stratigraphic information is correlated from exposed sections and related to surveyed cross sections. Additional heights were obtained from altimetry. A general postglacial chronology is proposed for Matzhiwin Creek based on the terrace stratigraphy and radiocarbon dates from bones in the terrace deposits.

The chronology of geomorphic events in Matzhiwin Creek is compared to other fluvial systems in the area to see whether similar periods of aggradation and incision have occurred. The presence of a regional pattern of terrace formation may indicate the influence of large-scale climate or baselevel changes.

## 3.2 The Study Area

Matzhiwin Creek, draining an area approximately 2700km$^2$ (Schoenfeld and Hammer 1991), is a tributary of the Red Deer River in the southern Alberta plains. The area is relatively flat with elevations varying from 700 - 760m asl, though badlands topography fringes the Red Deer River valley. Matzhiwin Creek flows from west to east for a distance of approximately 20km then turns north almost 90 degrees to join the Red Deer River. For approximately 8km upstream of highway 36 (fig.3.1) the creek is flanked with terrace remnants, the number of which vary from one to four depending on the location. Downvalley of highway 36, deep incision has produced steep valley sides and large areas of

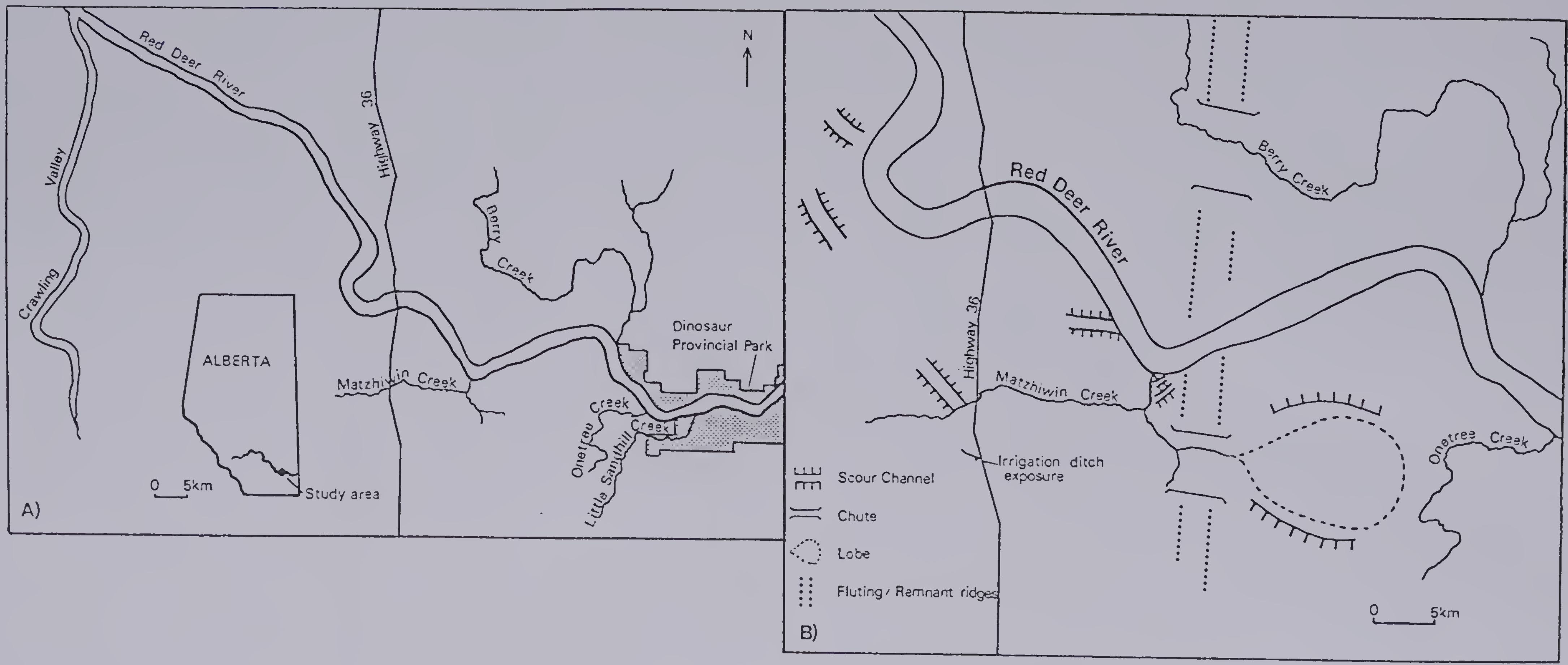



Fig.3.1(A). The location of Matzhiwin Creek and the surrounding area. (B) The main geomorphic features in the area around Matzhiwin Creek.

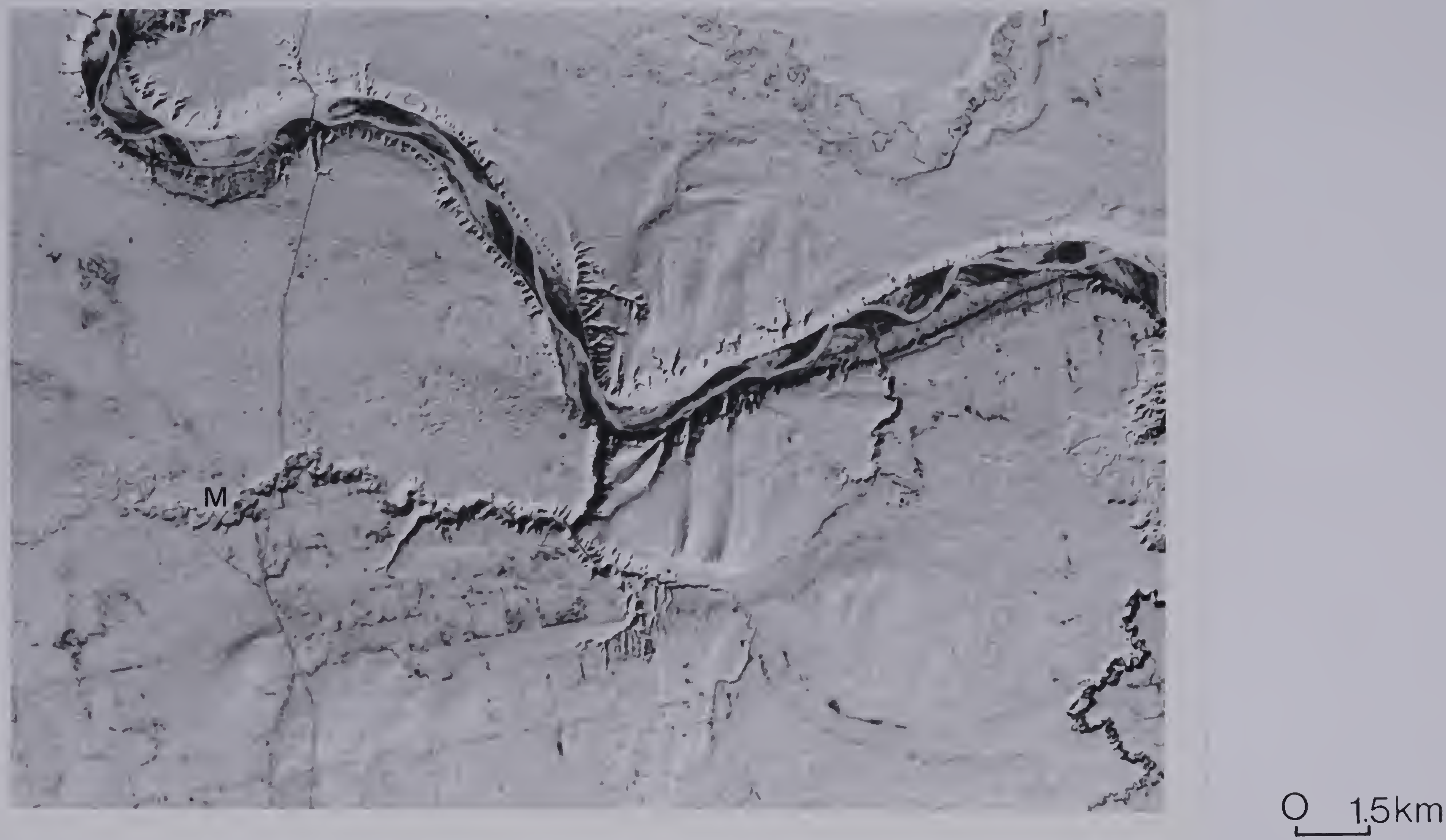



Fig.3.2. Satellite image of Matzhiwin Creek (m) and the surrounding area. The main geomorphic features are illustrated on fig.3.1(B).

exposed bedrock. There are no alluvial terraces in this reach though a well-defined upper erosional bench is present near the creek confluence with the Red Deer River. The bench is at an elevation of 690m asl and extends for a distance of approximately 6km. Below the bench there is an extensive, terracelike surface formed by truncated, coalescent alluvial fans.

The bedrock geology consists of marine and continental mudstones and sandstones deposited in and around a shallow interior sea during late Cretaceous time. The Judith River Formation (formerly Oldman Formation, MacLean 1971) is composed of weakly cemented and compacted sandstones and mudstones with occasional thin clay ironstone bands. The Formation is derived from fluvial and deltaic sediments (Koster 1984). Marine deposits of the Bearpaw Formation overlie the Judith River Formation and are clay-rich consisting of dark grey blocky shales and grey clayey sandstones (Koster 1984).

The oldest surficial deposits in the area are the gravels and sands of the Empress Formation (Whitaker and Christiansen 1972), formerly known as Saskatchewan Gravels and Sands (Rutherford 1937;Stalker 1968). The Empress Formation includes some Tertiary and Quaternary sediments between bedrock and the oldest glacial deposits. It consists of a lower unit of preglacial quartzite and sandstone lithologies with no Shield material and an upper unit consisting of proglacial sand and gravel including igneous, metamorphic and carbonate clasts (Christiansen 1992). The lower unit is found in preglacial bedrock valleys.

Preglacial valleys in southern Alberta have been mapped by Stalker (1961) and Tokarsky (1986). The preglacial drainage generally followed a similar trend to that of the present eastward-flowing rivers. Stalker (1961) observed that in southern Alberta the modern Red Deer River partially follows the preglacial Bow valley, referred to here as the preglacial Calgary valley (fig.3.3). The interpreted

preglacial Calgary valley thalweg trends west to east (fig.3.3) and is separated from a tributary valley by a bedrock high to the south of Matzhiwin Creek. This reconstruction suggests that Matzhiwin Creek has incised, at least partly, into the preglacial Calgary valley in its upstream end. However, the preglacial valley is aligned towards the northeast in this region and it is unclear whether the downstream end of Matzhiwin Creek has also incised into the preglacial valley (fig.3.3).

The preglacial Calgary valley is up to 30km wide in the study area and between 50-100m deep (Tokarsky 1986). Empress Formation deposits associated with the valley can be up to 10m thick (Alberta Environment 1991). Thick deposits of glacial diamicton filled the preglacial valleys during the late Wisconsinan glaciation.

Quaternary deposits include late Wisconsinan till deposited by the Laurentide ice sheet and various glaciolacustrine and glaciofluvial deposits. Postglacial fluvial erosion and mass movements have exposed the highly erodible Judith River Formation, forming a characteristic badland topography. The most extensive badlands are in the Dinosaur Provincial Park area which was scoured to bedrock by fluvial erosion during deglaciation (Bryan *et al.*1987). Elsewhere, thick deposits of glacial sediments in preglacial valleys retarded badland development (Beaty 1976). Other surficial deposits within this region include Holocene alluvial and aeolian deposits.

Southern Alberta has a continental, semiarid climate. At Brooks, approximately 30km south of the study area, July and January means are 18.1$^{0}$C and -14.1$^{0}$C respectively (Environment Canada 1982). The mean annual precipitation is 300 - 325mm with approximately 70% falling between May and September. Summer rains are often highly localised, intense, short duration, convectional rainfall (Bryan and Campbell 1980).

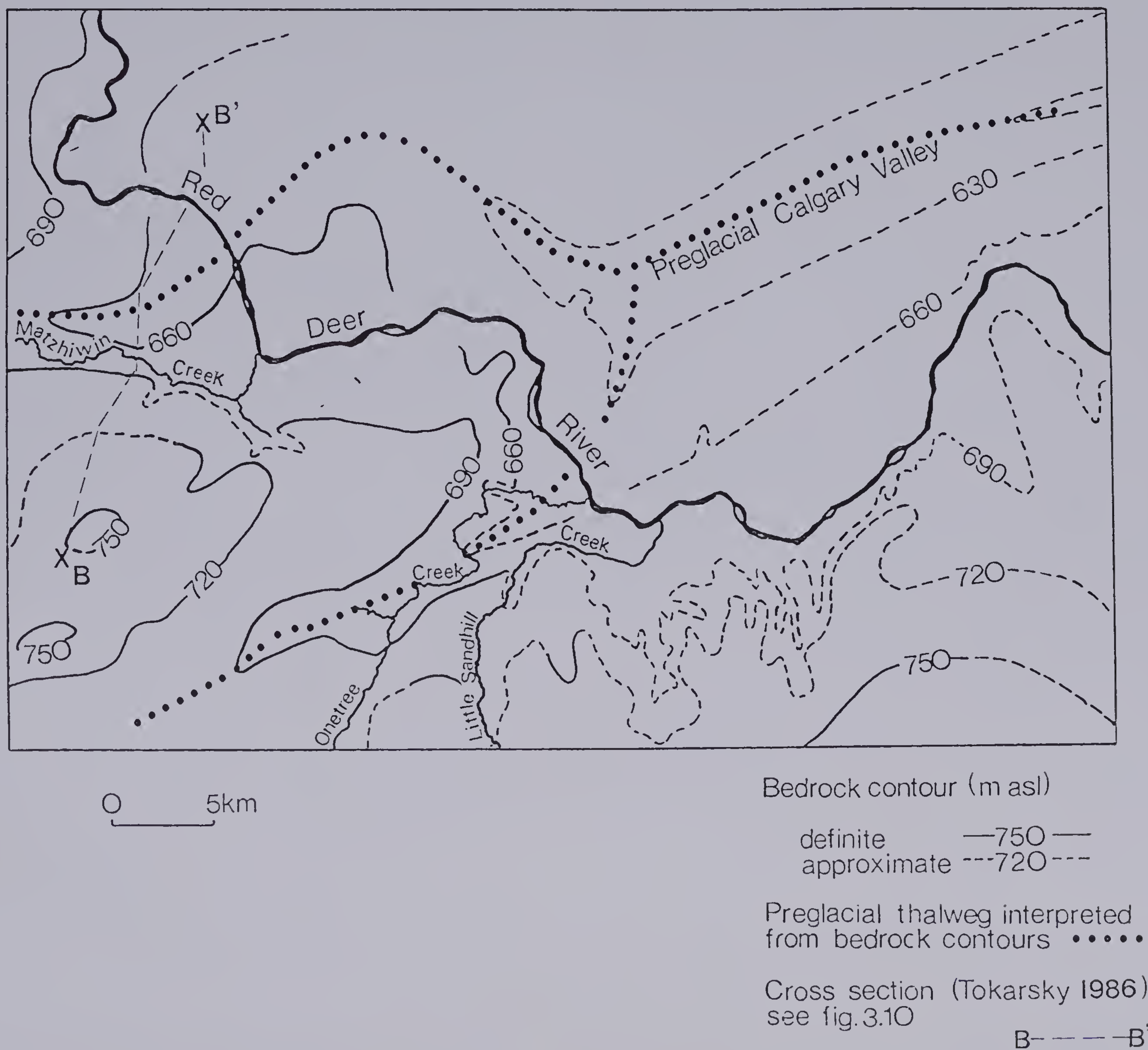



Fig.3.3. Subsurface bedrock topography of the area including interpreted thalwegs for the preglacial valleys (modified after Alberta Research Council 1970).

## 3.3 The postglacial evolution of fluvial systems in the region around Dinosaur Provincial Park.

The geomorphic evolution of Dinosaur Provincial Park is discussed in Bryan *et al.*(1987) and the glacial and postglacial stratigraphy are reviewed in Evans and Campbell (1992). Bryan *et al.*(1987) used the deglacial chronology proposed by Christiansen (1979) to determine the timing and position of Laurentide ice in the area. By ca.15 ka BP a series of large, interconnected, ice-dammed lakes existed to the south and southwest of the present position of the Red Deer River (Bryan *et al.*1987). As the ice retreated to the north and the northeast, proglacial lakes drained rapidly towards the east through a series of spillways. The ancestral Red Deer River acted as the main spillway; it initially flowed east at about 14-12 ka BP into Glacial Lake Regina (Christiansen 1979;Dyke and Prest 1987). Extensive sheet flooding may have been an initial response to ice retreat and proglacial lake drainage resulting in a mixed gravel-diamicton lag close to the prairie surface (Evans 1991).

The gravel lag (Evans 1991;Evans and Campbell 1992) directly overlies glacial diamicton. The gravel lag deposit is overlain in places by fluvial sands where subsequent channelisation occurred or by interbedded, massive or weakly laminated, medium to fine sands, silt and clay fines (Evans and Campbell 1992) deposited in prairie depressions during moist climatic periods. Two radiocarbon dates retrieved from ponded sediments on the prairie surface along Little Sandhill Creek (fig.3.1) suggest pond sedimentation began there prior to 9.1 ka BP and ended sometime after 7.1 ka BP (Campbell and Evans 1990). An overlying deposit of aeolian sands and silts above the ponded sediments may record a climatic change to more arid conditions in the area. Extensive sand dune deposits upwind of the study area provide a likely source for these aeolian sediments. Widespread aeolian deposits in nearby Dinosaur Provincial

Park are partly dated at 5.4 ka+/-800 BP (ALPHA-2074) (Bryan *et al.*1987).

Postglacial spillway incision in the Red Deer River was a two-stage process involving an initial broad valley stage with extensive lateral scouring followed by a period of narrow, deep entrenchment, resulting in a valley-in-valley form. Bryan *et al.*(1987) identified extensive surfaces within Dinosaur Provincial Park at about 690 and 680 m asl that are interpreted to be the result of the broad valley stage. The broad valley stage was followed by a period of deep incision, possibly a result of glacioisostatic rebound following deglaciation (Bryan *et al.*1987) though at present there are no dates available to determine the timing of this event. MacPherson (1968) found fluvial gravels (in the lower Red Deer valley) which lie some 40m below the present stream bed. These gravels are interpreted to be the result of immediate postglacial incision and they possibly relate to the period of narrow, deep entrenchment. Incision in the Red Deer River spillway stimulated the development of tributary channels along the flanks of the main valley. Many of the channels have a strong north - south orientation apparently reflecting structural control by regional joint sets (Koster 1984).

Badland formation followed extensive scouring by meltwaters which stripped the thin glacial deposits and exposed the highly erodible bedrock. The increased sediment supply to the Red Deer River during badland formation possibly resulted in a major period of aggradation (MacPherson 1968;Bryan *et al.*1987). A similar depositional phase in the lower Falcon valley in Dinosaur Provincial Park, a tributary of the Red Deer River, is interpreted to be the result of a rise in local baselevel caused by channel aggradation in the Red Deer River (O'Hara and Campbell 1993). Channel aggradation was followed by the deposition of alluvial fan sediments (MacPherson 1968;O'Hara and Campbell 1993) which are interpreted as indicating a trend towards

arid climatic conditions. Fan deposition ceased around 6.0 - 5.0 ka BP when aeolian sediments were deposited on the fans. A thermoluminescence date of 5.4 ka+/-800 BP (ALPHA-2074) has been obtained from near the base of aeolian sediments found extensively in Dinosaur Provincial Park (Bryan *et al.*1987).

Subsequent incision in the Red Deer River produced a series of terraces in the valley fill (MacPherson 1968). In the lower Falcon valley the alluvial fan deposits were truncated and a lower terrace formed (O'Hara and Campbell 1993).

### 3.4 The geomorphology of Matzhiwin Creek

The Matzhiwin Creek study area extends from an elevation of 712m asl to the confluence with the Red Deer River at 638m asl, over a distance of approximately 27km (fig.3.4). The long profile (fig.3.4) was constructed from 1:50 000 topographic maps with a 25' (7.62m) contour interval. Stream distance between contour elevations was measured with a distancing, electronic planimeter.

The long profile consists of three sections; a downstream reach of deep incision with exposed bedrock and badlands topography; a central reach where extensive slumping has occurred; and an upstream reach where alluvial terrace remnants dominate the valley (fig.3.4). The valley continues for some distance upstream of the terrace-dominated reach but as the depth of valley incision decreases the terrace remnants merge and become indistinct.

In general, the long profile (fig.3.4) displays a convex-up form also observed in other prairie creek systems in central and southern Alberta (Rains and Welch 1988; Donnelly 1990;Rains *et al.*1994). Rapid incision rates of the Red Deer River in the late glacial and early Holocene resulted in steep, convex-up profiles in downstream reaches of tributary creeks. Small creeks were unable to maintain equally rapid rates of incision due to their intermittent

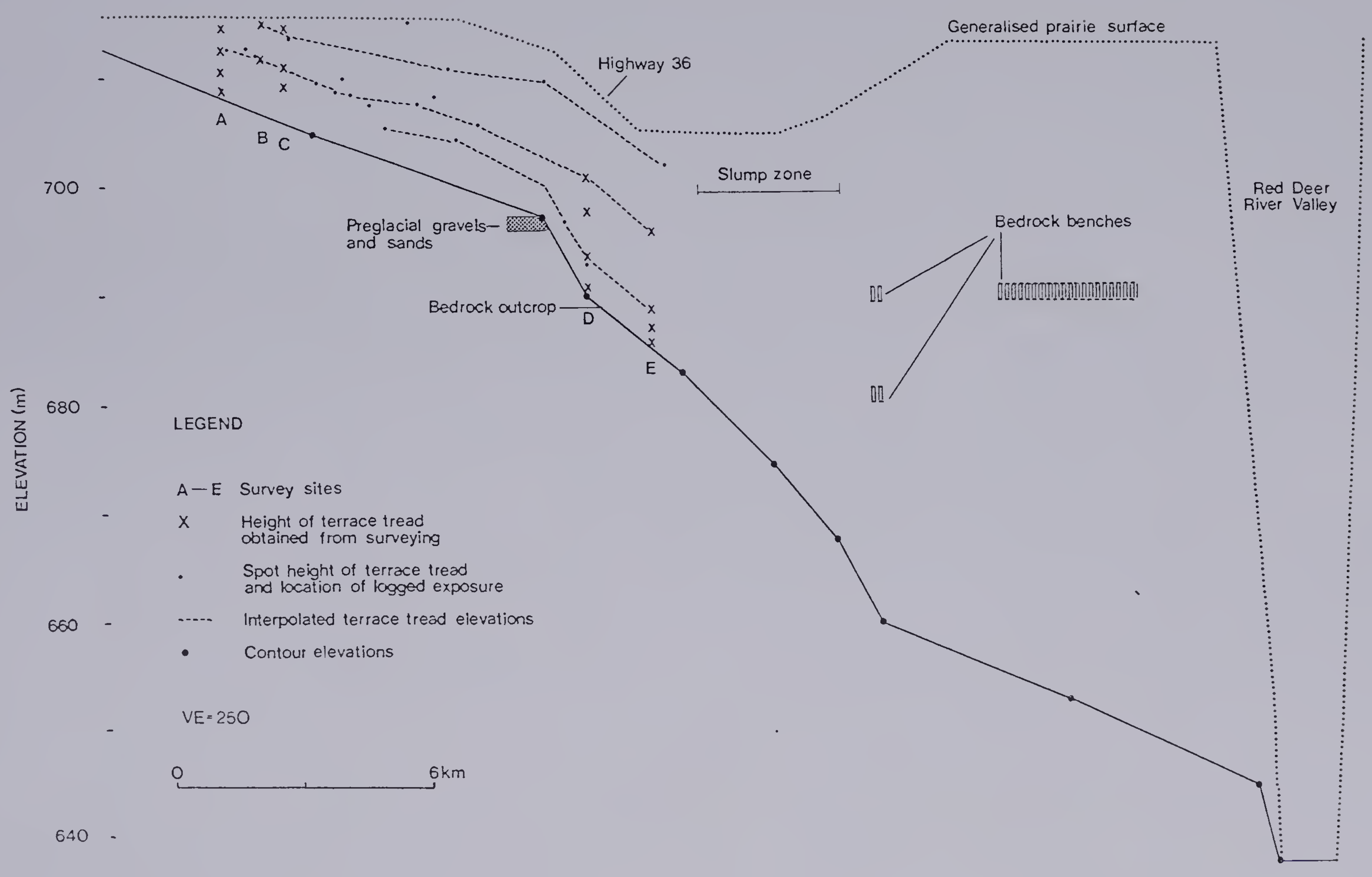



Fig.3.4. Vertically exaggerated long profile of Matzhiwin Creek emphasizing major geomorphic and stratigraphic relationships.

discharges and smaller drainage basin sizes (Rains *et al*.1994). Matzhiwin Creek has incised up to 80m at its confluence with the Red Deer River.

In the downstream reach of Matzhiwin Creek deep incision in the underlying Cretaceous bedrock has not favoured alluvial terrace preservation, though bedrock benches are evident on the valley sides. An upper, paired bedrock bench lies approximately 40m above the channel at an elevation of 690m asl and is relatively continuous in this valley reach (fig.3.4). A lower, less extensive bedrock bench is found approximately 30m above the present channel at an elevation of 680m asl (fig.3.4). Also in this downstream reach is a lower terracelike surface 3-8m above the present channel. This surface consists of an almost continuous apron of truncated, coalescent alluvial fans which line the valley sides. Similar truncated fans border the lower Falcon valley in Dinosaur Provincial Park (O'Hara and Campbell 1993).

In the central reach extensive slumping of the valley sides makes the identification of terrace treads difficult (fig.3.4). Slope instability is common throughout southern Alberta (DeLugt and Campbell 1992).

Well preserved terraces are present in the upstream reach of Matzhiwin Creek for approximately 8km upstream of highway 36 and 1-2km downstream (fig.3.4). There are three main paired terrace surfaces and some intermediate, unpaired, terrace remnants; T1 represents the highest terrace tread and T4 is the modern floodplain which rarely exceeds 1m in height above the creek. Fig.3.5 shows the distribution of the paired terraces within the upstream reach. Subtle differences in height between T2 and T3 prevents them from being distinguished as separate surfaces on fig.3.5. The generalised stratigraphic relationships of T1-T4 are shown in cross section in fig.3.6. The location of survey transects is shown on figs.3.4 and 3.5.

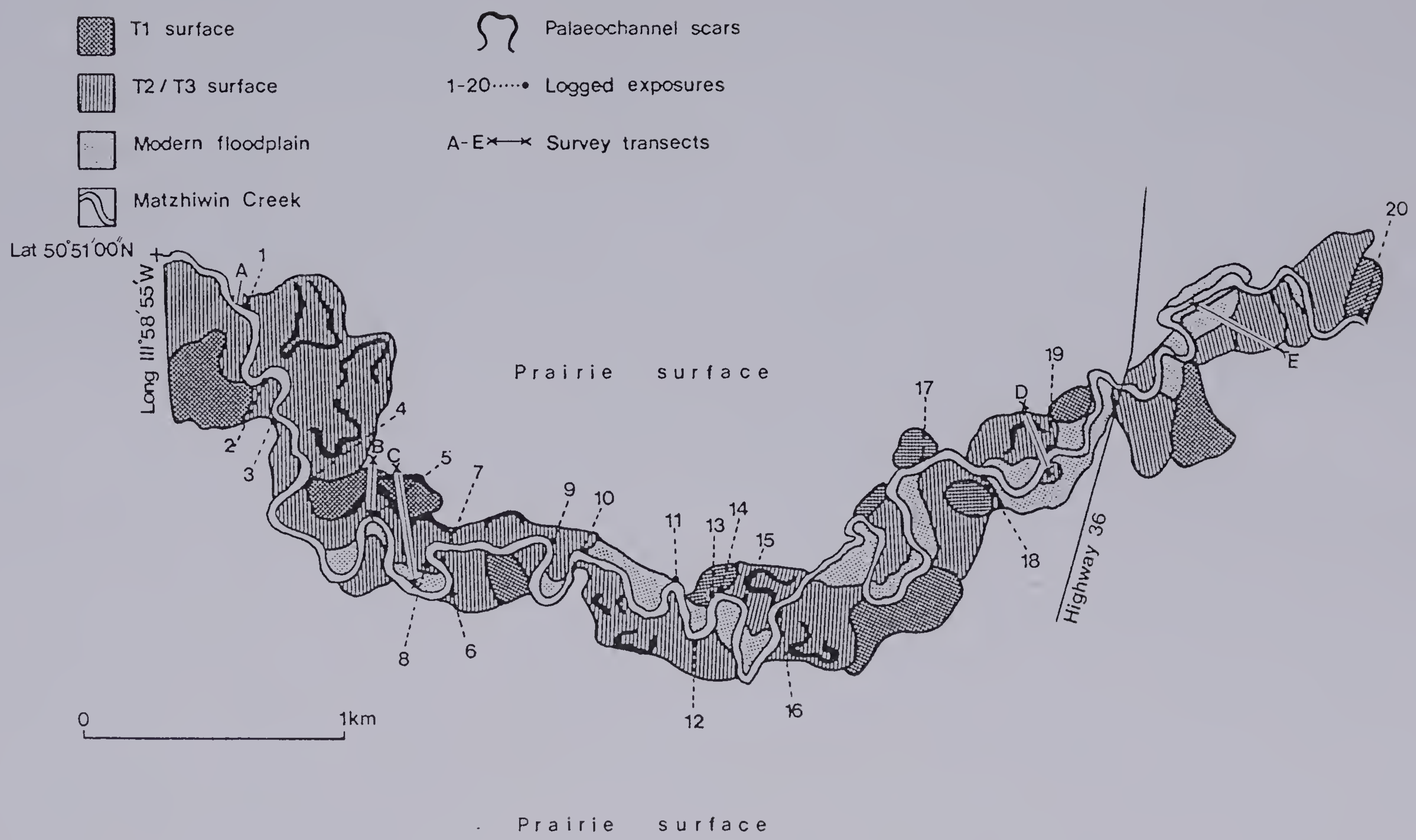



Fig.3.5. Distribution of paired alluvial terraces, palaeochannel scars, logged exposures and survey transects for the terrace dominated sector of Matzhiwin Creek.

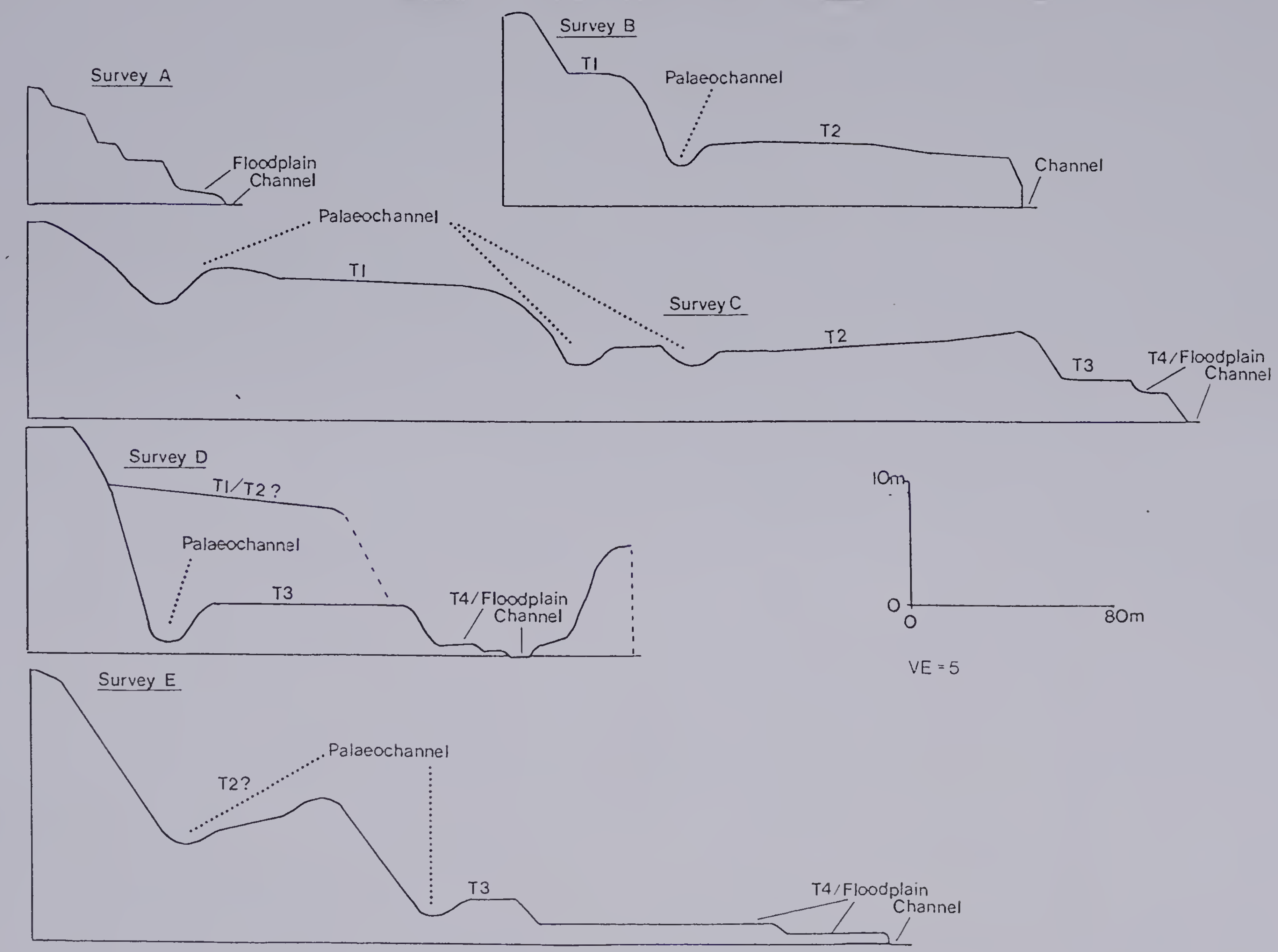



Fig.3.6. Valley cross sections from survey transects A-E showing various terrace remnants, palaeochannel scars, modern floodplain and present channel positions.

The highest surface, T1 is found 1-3m below the prairie surface and 9-18m above the present channel. The extensive T2 surface forms the dominant surface in the upstream reach. It is 3-8m below the prairie surface and 5-7m above the present channel; the T2 surface contains numerous palaeochannels. The less extensive T3 surface stands 3-4m above the channel and is only separated by 2-3m from the T2 surface. The modern floodplain, T4 forms the lowest surface above the present channel.

The prairie surface is relatively flat on either side of the valley and is at an approximate elevation of 716m asl. A large depression in the prairie surface in the central reach of the valley represents a large scour channel which has incised approximately 10m below the present prairie surface (fig.3.4). Numerous other scour channels cross the prairie surface (figs.3.1 & 3.2). These and other related fluvially eroded features are assumed to represent abandoned channels following the drainage of the former glacial lakes (Bryan *et al*.1987).

Matzhiwin Creek has incised through the Duchess dune field, an area of extensive aeolian deposits consisting of sand sheets and parabolic dunes. The dune field is approximately 120km$^2$ and probably formed shortly after proglacial lake drainage. The aeolian deposits form an important source area for windblown material which is widespread on terraces and other surfaces in the Matzhiwin valley.

East of Matzhiwin Creek a large glacial flute/ remnant ridge trends northeast - southwest (figs.3.1 & 3.2). It has been dissected by Berry Creek, the Red Deer River and the main tributary of Matzhiwin Creek. The Matzhiwin Creek breach forms an opening approximately 0.75km wide and over 40m deep. A large depositional lobe is also evident approximately 6km to the east of the breach (fig.3.1 and 3.2).

### 3.5 The valley fill

The valley fill generally consists of glacial diamicton, gravels, fluvial sands, overbank fines and aeolian sands and silts. Sands are assigned a fluvial or aeolian origin on the basis of stratigraphic and sedimentologic criteria. Aeolian sands drape the underlying deposits and consist of well sorted, massive, fine-grained sands with interbedded palaeosol horizons. In places a brown Chernozemic soil has developed in the upper layers of aeolian sediments. Fluvial sands range from coarse-grained, poorly sorted sands with incorporated gravels to medium/ fine-grained, massive, ripple or planar-bedded sands. The fluvial sands were typically overlain by overbank fines. The general stratigraphic relationships of the valley fill, based on information obtained from logged exposures, are shown on fig.3.7. The logged exposures are illustrated on fig.3.8.

Surface and T1 exposures

Exposure 11 (fig.3.8) records the sedimentary sequence from the present stream bed to the prairie surface. It consists of glacial diamicton >12m thick overlain by a poorly sorted gravel lag. The lag consists of quartzites and shield boulders up to 12cm (a-axis). The lower contact with the diamicton appears to be abrupt and erosional, though a gradational contact actually exists. The lag is interpreted to be a winnowed deposit derived from eroded diamicton and corresponds to a similar extensive deposit identified in adjacent areas by Evans (1991). Well sorted, massive silts and fine-grained sands (2.5Y 4/4) overlie the gravel lag. These are interpreted as aeolian deposits and contain up to four dark palaeosol horizons.

Exposures 4, 14, 17 and 20 (fig.3.8) record the valley fill underlying the T1 surface. All these sections contain thick exposures (8-14m) of diamicton. A gravel lag overlies the diamicton in all T1 exposures and closely resembles the lag deposit in exposure 11. At exposures 4 and 14 massive

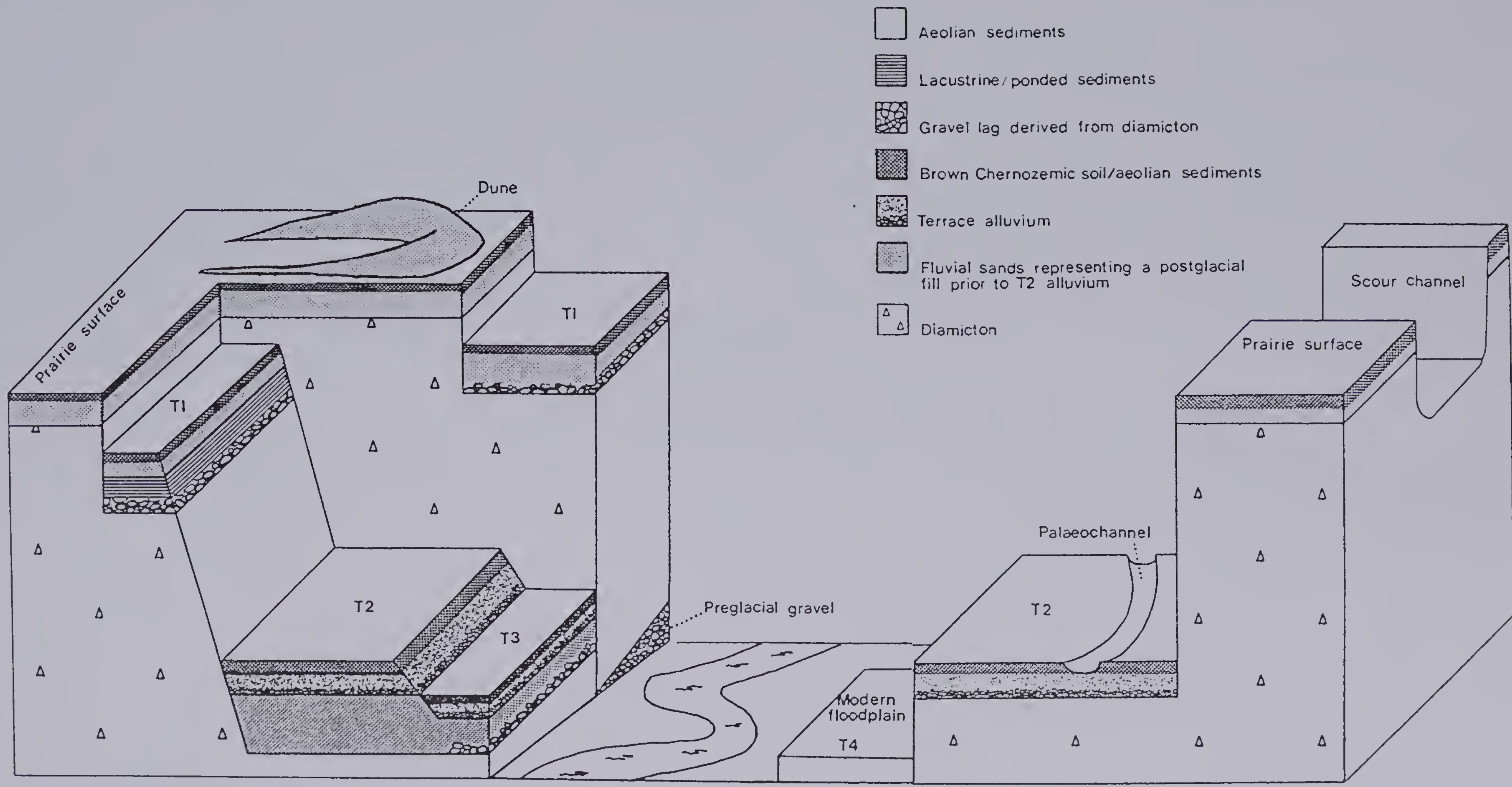



Fig.3.7. Generalised valley cross section and underlying deposits in the upstream reach based on information obtained from logged exposures (see fig.3.8).

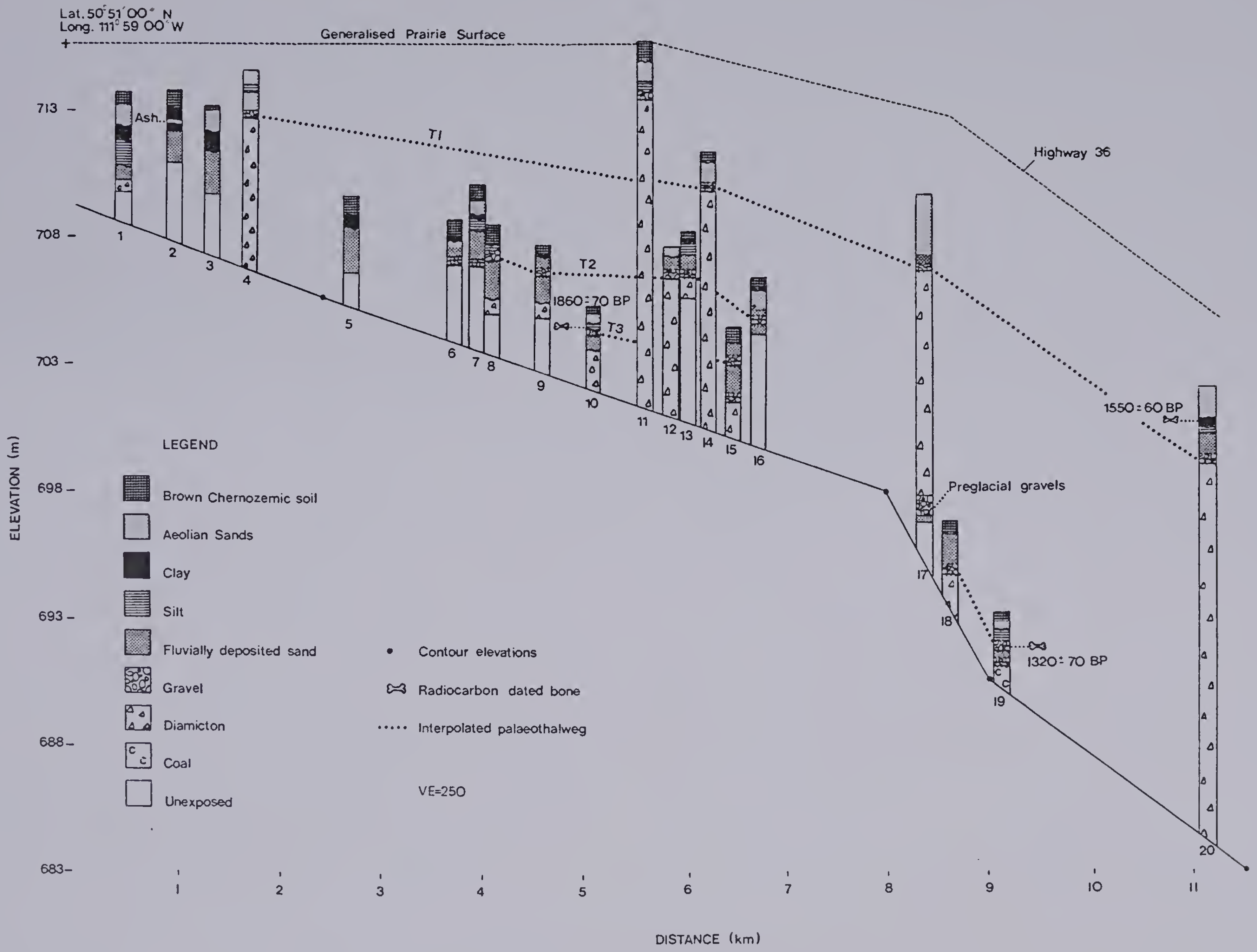



Fig.3.8. Logged exposures in the main study reach illustrating general stratigraphic relationships of the valley fill.

silts and fine-grained sands (2.5Y 4/4) overlie the gravel lag and are interpreted as aeolian in origin displaying up to four palaeosol horizons. However, at exposure 17 coarse-grained sands (10YR 6/2) overlie the gravel lag and display a fining-up sequence suggesting a fluvial origin. The upper unit consists of massive fine-grained sands interpreted as aeolian in origin, with two palaeosol horizons in the upper 0.6m of the deposit.

At exposure 20 (fig.3.8) a deposit 0.8m thick consisting of weakly laminated, medium to fine-grained sands (10YR 7/1) overlies the gravel lag. Similar deposits were recorded by Campbell and Evans (1990) and Evans and Campbell (1992) and interpreted to be ponded sediments deposited during moist climatic conditions in the early postglacial period when the prairie surface became waterlogged. At site 20 (fig.3.8), light grey, weakly laminated, compact silts conformably overlie the sand unit. Pedogenesis has occurred in the upper part of this deposit forming a light grey, clay/silt horizon approximately 0.2m thick. Bison bone from this palaeosol horizon which caps the underlying ponded sediments has yielded a $^{14}C$ date of 1550+/-60 BP (TO-4579). Massive sands (2.5Y 4/4) which form the upper unit of this exposure are interpreted as aeolian in origin and contain four palaeosol horizons.

Poorly imbricated gravels underlie the glacial diamicton at exposure 17 with an upper, erosional contact (figs.3.8 & 3.9). The exposed gravel unit is 0.8-1.0m thick and consists of well rounded, quartzite pebbles in a silt matrix with no Shield lithologies. In some cases the pebbles are fractured. Medium-grained, light grey, well sorted, planar crossbedded sands (10YR 6/1) underlie the gravel unit. The gravels and sands are interpreted as preglacial (Empress Formation) as they contain no Shield lithologies and underlie thick glacial deposits. The preglacial gravels are found at an elevation of 697m asl at this site and are approximately 2m above the present stream bed. The location

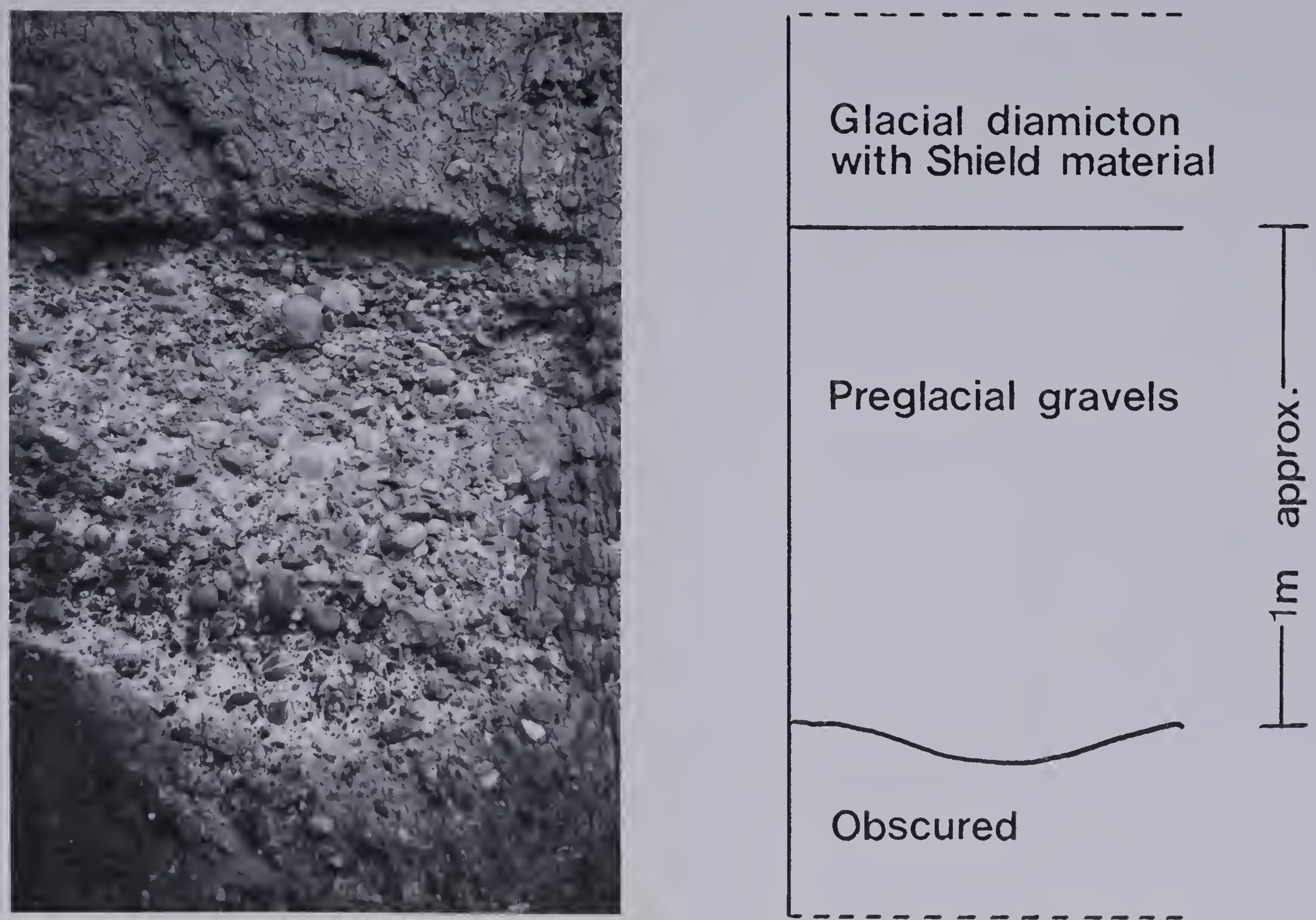



Fig.3.9. Preglacial gravels near the base of exposure 17 which contain no Shield material. The sharply defined, upper, erosional surface is capped by a clay-rich diamicton which contains Shield material and is interpreted as late Wisconsinan in age.

Fig.3.10. See opposite page. The preglacial Calgary valley. (A) The location of sites where preglacial gravels have been located in and around Matzhiwin Creek. Elevations of preglacial gravels are calculated from well log information (Alberta Environment 1991), site 17 (this study) and hydrogeologic cross sections (Tokarsky 1986). (B) The elevation of preglacial gravels below the surface between Bassano and Jenner was derived from the above sources. (C) Preglacial Calgary valley cross sections between points A-A' and B-B' (Tokarsky 1986), bedrock formations and various surficial deposits are undifferentiated.

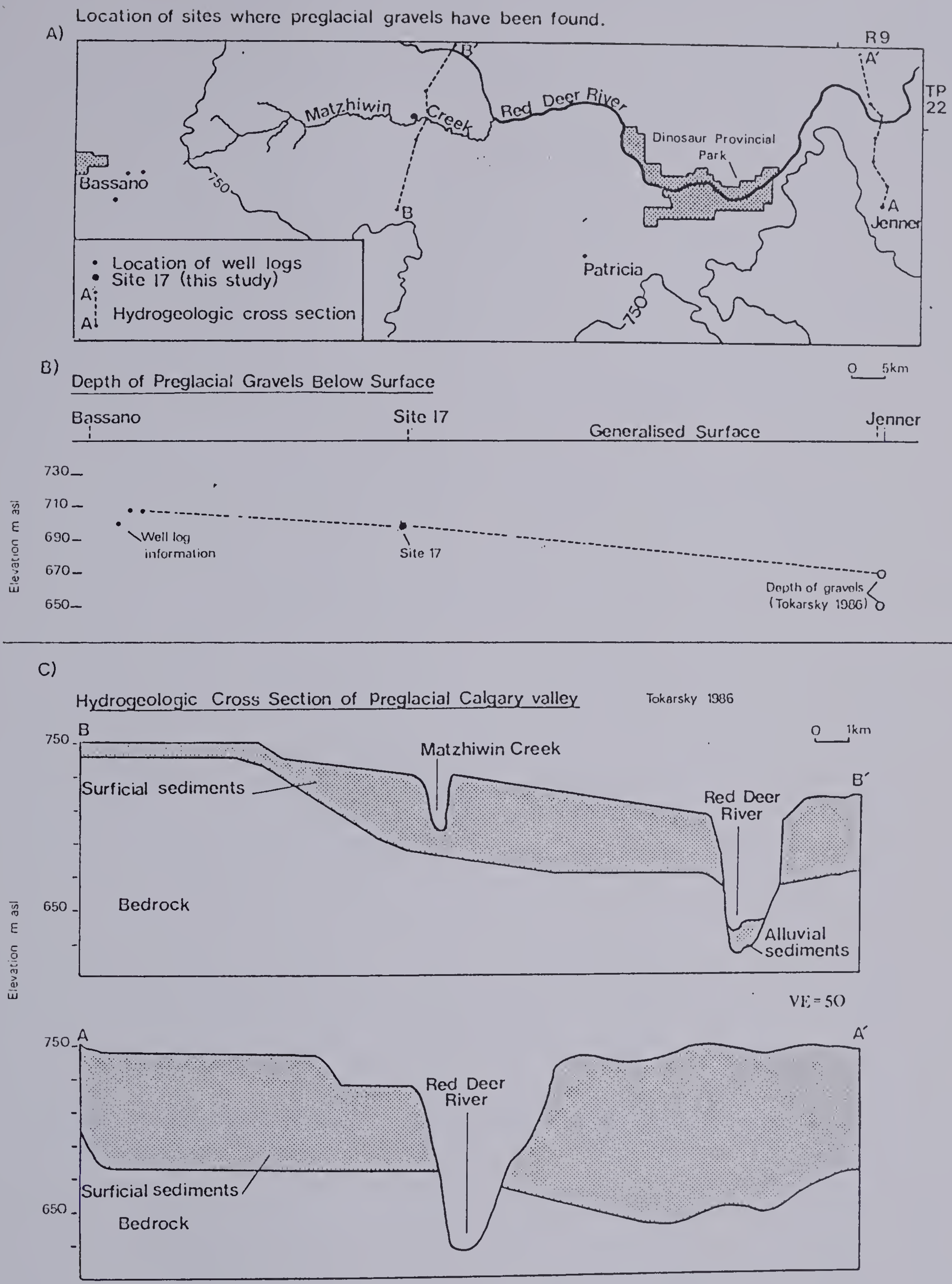

A) Location of sites where preglacial gravels have been found.
R9
A'
TP 22
B'
Matzhiwin
Creek
Red Deer River
Dinosaur Provincial Park
Bassano
750
B
A
Jenner
Patricia
750
Location of well logs
Site 17 (this study)
A
A Hydrogeologic cross section
0 5km
B) Depth of Preglacial Gravels Below Surface
Bassano
Site 17
Generalised Surface
Jenner
730
710
690
670
650
Elevation m asl
Well log information
Site 17
Depth of gravels (Tokarsky 1986)
C) Hydrogeologic Cross Section of Preglacial Calgary valley
Tokarsky 1986
750
B
0 1km
Matzhiwin Creek
B'
Surficial sediments
Red Deer River
650
Bedrock
Alluvial sediments
Elevation m asl
VE = 50
750
A
A'
Red Deer River
Surficial sediments
650
Bedrock

FIG. 3.10

of the preglacial gravels and sands (fig.3.4) corresponds to a major knickpoint in the long profile. It is likely that this unit inhibits stream incision and possibly enhances rates of lateral stream migration.

Matzhiwin Creek has incised, at least partly, into the preglacial Calgary valley (Stalker 1961;Tokarsky 1986) (fig.3.3). This is confirmed by the thick deposits of glacial diamicton in various sections and the preglacial gravels at site 17 (fig.3.8). Figure 3.10 shows the location of sites around the study area where preglacial gravels have been observed which are likely associated with the preglacial Calgary valley. Near Bassano, well logs identify similar gravels at an approximate elevation of 700m asl (Alberta Environment 1991). Gravels in the preglacial Calgary valley have also been recorded at an elevation of 670m asl north of Jenner (Tokarsky 1986). A generalised long profile of the preglacial Calgary valley is shown on fig.3.10 based on known elevations of preglacial gravels. Fig.3.10 also illustrates partial cross section profiles of the preglacial Calgary valley to the west and east of Dinosaur Provincial Park (Tokarsky 1986).

T2 exposures

Exposures 1-3, 5-9, 12, 13 and 16 record the sedimentary sequence beneath the T2 surface (fig.3.8). A lower gravel unit overlies diamicton with a gradational contact and contains boulders up to 15cm in a-axis length with incorporated Shield clast lithologies in exposures 6, 7, 12 and 13 (fig.3.8). Due to the size of boulders in this deposit and the nature of the contact, it is interpreted to be a lag deposit derived from the eroded diamicton and closely resembles the upper gravel lag deposit observed in surface and T1 exposures. A basal sand unit consisting of coarse to medium-grained, horizontally and planar bedded sands (2.5Y 6/2) with relatively high angle foresets (fig.3.11) directly overlies diamicton in places. The basal

Fig.3.11. Planar-crossbedded sands (exposure 8) found in numerous T2 and T3 exposures either directly overlying diamicton or a coarse gravel lag. Flow was from west to east (right to left).

sand unit generally fines upwards and shows some degree of oxidation and is interpreted to be fluvial in origin. The lower sand unit was observed at exposures 1-3, 5, 8, 9 and 16 (fig.3.8).

An upper gravel unit was identified at exposures 8,9 and 16 (fig.3.8) and consists of small, well rounded gravels in a coarse-grained sand matrix. The gravels have a maximum a-axis length of 6cm and an erosional, basal contact with the underlying, lower sand unit. The upper gravel unit is overlain by fluvial and aeolian sands and silts. In some T2 exposures clays overlie this sand/ silt unit capped by a well developed, brown Chernozemic soil. The clay deposits are interpreted as representing overbank fines or ponded sediments possibly in an oxbow environment. In exposure 2 at a depth of approximately 1.5m, a distinctive, isolated, light grey tephra band, ca. 3.0cm thick, is interbedded in a relatively thick band of clay overlying a unit of fluvial sands (figs.3.8 and 3.12). Electron micropobe analysis (Geology Department, University of Alberta) of the glass shards produced indeterminate results. The tephra is tentatively interpreted as Mazama ash based on its stratigraphic position and the location of the study area in relation to the distribution of known, identified postglacial tephra deposits. Mazama ash has been assigned an age of about 6.8 ka BP (Bacon 1983).

In exposures 1, 7, 8 and 13 (fig.3.8) compact, light grey silts (2.7Y 6/2) conformably overlie sands and gravels and are generally overlain by clay deposits. The weakly laminated silts are interpreted as representing ponded sediments. Fig.3.13 shows the thick deposits of aeolian sands which overlie T2 alluvium upstream of exposure 1.

T3 exposures

Exposures 10, 15, 18 and 19 (fig.3.8) reveal the underlying T3 alluvium. Exposure 15 consists of a lower gravel unit containing boulders with Shield lithologies, up to 12cm long

Fig.3.12. A distinctive, isolated tephra band located within a relatively thick clay deposit at exposure 2.

Fig.3.13. Thick deposits of aeolian sands overlying T2 alluvium upstream of exposure 1. In places a brown Chernozemic soil has developed in the upper layers of this deposit.

in a coarse sand matrix. The basal contact with the underlying diamicton is gradational. The gravel lag is overlain by well sorted, planar bedded sands (2.5Y 6/2) with relatively high-angle foresets. The gravels are interpreted to be a lag deposit derived from the eroded diamicton overlain by fluvial sands.

An upper gravel unit overlies the sands and consists of small, well sorted, rounded gravels with a maximum a-axis length of 5cm. The lower contact with the sands is erosional.

At site 10 (fig.3.8) a lower sand unit (2.5Y 6/2) directly overlies diamicton. An upper gravel unit consisting of small rounded gravels <5cm in length overlies the sands with an erosional basal contact. The upper gravel unit is overlain by a 0.3m unit of very compact, microlaminated, olive grey silts, interpreted as ponded sediments, and fine aeolian sands (fig.3.14). Bone fragments from the silt unit were $^{14}C$ dated at 1860+/-70 BP (TO-4577) (fig.3.8).

The deposits observed in T3 exposures 10 and 15 closely resemble the sequences observed in T2 alluvium. They display an upper gravel layer consisting of gravels with a maximum a-axis length of 6cm which have incised into a lower sand unit (fig.3.7). Fluvial and aeolian deposits overlie the upper gravel unit. The lower sand unit, which either directly overlies diamicton or a coarse gravel lag (site 15), likely represents an earlier valley fill into which T2 alluvium has been inset, resulting in coarsening upward sequences in exposures 8,9 and 16 (fig.3.8). In places, T2 gravels have been incised into diamicton producing a gravel lag containing large boulders up to 15cm in length and removing the older, basal sands; sites 12 and 13 (fig.3.8).

A similar scenario is suggested for the upper gravel unit which overlies a basal sand unit in exposures 10 and 15 (fig.3.8), underlying the T3 surface. The basal sands represent an earlier valley fill into which T3 alluvium has been inset. The basal sands observed in exposures 10 and 15

Fig.3.14. Bone fragments in T3 alluvium, exposure 10. The bone fragments (X) were in a compact silt unit overlain by aeolian sands and yielded a $^{14}C$ date of 1860+/-70 BP (TO-4577).

correspond stratigraphically with the basal sands observed in T2 alluvium in exposures 1-3,5,8,9 and 16 (fig.3.8). It is suggested that the gravel lag observed at the base of exposure 15, overlying diamicton, and the basal sands found in numerous T2 and T3 exposures represent a period of valley incision and aggradation prior to deposition of T2 and T3 alluvium. Sedimentary structures in the older, basal sands suggest deposition under relatively high flow conditions. T2 and T3 alluvium appears to have been inset into this older valley fill sometime later, resulting in an upper gravel layer in exposures 8,9,10,15 and 16 (fig.3.8). The interpreted palaeothalwegs for T2 and T3 channels are shown on fig.3.8 and are in places underlain by the older, basal sands.

Exposure 19 (fig.3.8) reveals a deformed basal bedrock unit (Judith River Formation) of coal (fig.3.15). The deformed bedrock is overlain by poorly sorted, fractured gravels in a fine-grained sand/ silt matrix and appears to contain no Shield clast lithologies. It is unclear as to the secondary processes involved in its deformation. Deformation most likely resulted from glacial loading. The gravel unit overlying the bedrock resembles the preglacial gravels (Empress Formation) observed upstream at site 17 (fig.3.8). However, it is unclear as to when the gravels were deposited; *i.e* whether they are preglacial in origin or they represent glacially reworked deposits. The lower gravel unit is overlain by medium to coarse-grained, light grey sands which contain ripple laminations and what may be dewatering structures.

An upper gravel unit containing boulders up to 15cm in length with incorporated Shield clast lithologies overlies the sands with an erosional contact. A bone fragment from these upper gravels yielded a $^{14}C$ date of 1320+/-70 BP (TO-4576) (fig.3.8). Fine-grained sands and silts overlie the upper gravels capped by a brown Chernozemic soil. The upper gravels are interpreted to represent T3 alluvium which has

Fig.3.15. Deformed Judith River Formation bedrock at exposure 19. The bedrock is overlain by a lower gravel unit containing no Shield material and fluvial sands. Disruption of the lower gravel unit by two upfolds of bedrock indicates post-gravel deformation. The upper gravel unit contains Shield material and is overlain by fluvial sands and aeolian material. Bone from the upper gravel unit dated 1320+/-70 BP (TO-4576).

been inset into an underlying, older sand deposit. Deep incision at this site and the removal of diamicton is reflected in the fact that T3 gravels are located close to bedrock. Large boulders incorporated in the upper gravel unit represent lag deposits derived from incision of the diamicton.

Large rounded clasts up to 8cm in a-axis length in a coarse sand matrix overlie diamicton at exposure 18 (fig.3.8). The gravel lag is overlain by medium-grained, well sorted, massive sands approximately 1m thick.

Alluvial fan deposits

In the downstream reach of Matzhiwin Creek deep valley incision has exposed Judith River Formation bedrock and a badland topography has formed. Coalescing alluvial fans line the lower part of the valley sides. These fans have been truncated at their distal ends by the creek to form a lower, extensive, terracelike surface approximately 3-8m above the present channel. The alluvial fan deposits consist of microlaminated clays, silts and fine sand. Pockets of gravels exposed in many sections are associated with gully systems which formerly incised into the fan surface (fig.3.16). In places fine, aeolian sands and silts overlie the fan surfaces. Similar depositional sequences in the lower Falcon valley in Dinosaur Provincial Park are interpreted as being associated with more arid conditions in the early to mid Holocene. Fan deposition ended around 5.0 ka BP following the widespread deposition of aeolian silts and fine-grained sands (O'Hara and Campbell 1993).

## 3.6 Chronology and regional correlations

Early postglacial

The valley of Matzhiwin Creek was incised during the early postglacial period when the prairie surface was extensively scoured by easterly draining lake and glacial meltwaters during Laurentide ice retreat to the northeast. Fig.3.17

Fig.3.16. Truncated alluvial fan deposit near the confluence with the Red Deer River. The deposit consists of microlaminated clays, silts and fine sands with discontinuous lenses of gravels.

Fig.3.17(A). Glacial Lake Bassano drains towards the east around 15-14 ka BP (Bryan *et al*.1987). During initial drainage lake water must have been >730m asl in order to breach the glacial flute/ remnant ridge. Extensive scouring by meltwaters produced numerous scour channels on the prairie surface (Evans 1991) and the widespread gravel lag in the upstream reach of Matzhiwin Creek underlying the T1 surface.

(B) Incision continued through the flute/ remnant ridge to approximately 700m asl in the early Matzhiwin valley as meltwaters become increasingly channelised. Around this time broad valley surfaces form in the Red Deer River valley at 680-690m asl (Bryan *et al*.1987). An extensive bedrock bench in the downstream reach of Matzhiwin Creek at 690m asl (fig.3.4) may relate to the upper surfaces in the Red Deer River valley or structural control from preglacial gravels (fig.3.4).

(C) Deep incision in the Red Deer River follows to approximately 610m asl, 20-40m below the present stream bed (MacPherson 1968;Tokarsky 1986) triggering deep incision in the downstream reach of Matzhiwin Creek and flow reversal in the tributary valley which flows through the flute (fig.3.1).

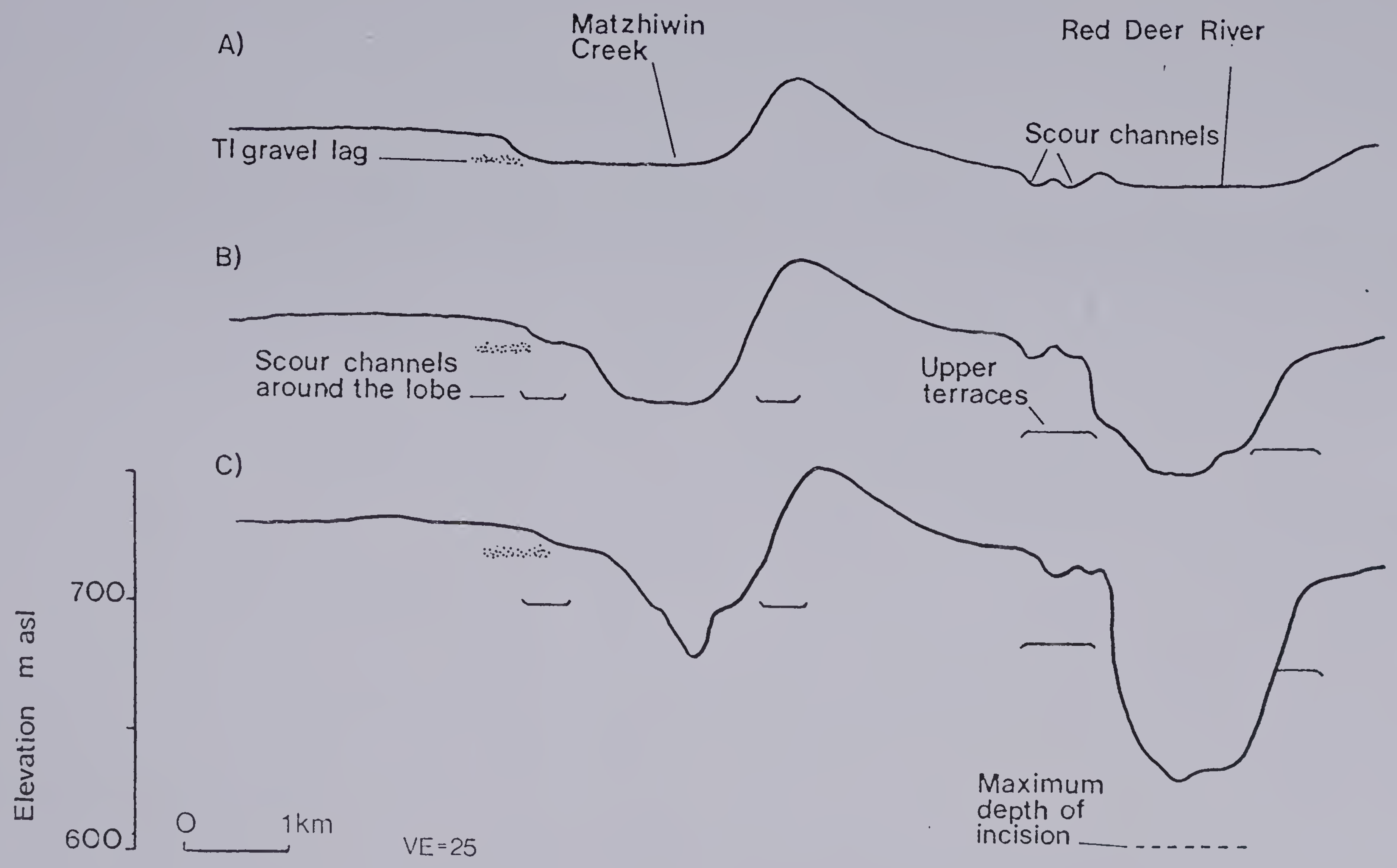



Fig.3.17. The early postglacial evolution of Matzhiwin Creek and surrounding area. The transect follows the northeast - southwest trending flute/ remnant ridge (fig.3.1). For descriptions see opposite page.

summarises the early postglacial evolution of the Matzhiwin Creek area. Three distinct phases are illustrated; extensive surface scouring by meltwaters (Evans 1991), broad valley incision (Bryan *et al*.1987) and finally deep, narrow incision in the Red Deer River (MacPherson 1968;Bryan *et al*.1987).

The maximum elevation of the lake surface in the study area is unknown. During the initial stages of drainage, however, lake water must have been above 730m asl in order to overtop and breach the topographic high formed by the glacial flute/ remnant ridge east of Matzhiwin Creek (fig.3.1). Extensive surface scouring by meltwaters led to erosion of glaciolacustrine sediments and a winnowed gravel lag close to the prairie surface derived from erosion ofthe late Wisconsinan till (Evans 1991). During this time numerous scour channels were carved 5-10m below the prairie surface at an approximate elevation of 705-715m asl (fig.3.17a). The main scour channels are illustrated in fig.3.1. The gravel lag observed overlying diamicton in the surface and T1 exposures and the large scour channel carved into the valley side in the upstream reach of Matzhiwin Creek (figs.3.4 & 3.8) are interpreted to relate to this extensive surface scouring by meltwaters. The surface/ T1 gravel lag in Matzhiwin Creek is located up to 5m below the surface ranging from 702-714m asl and corresponds stratigraphically with the numerous scour channels on the prairie surface. Because of the similar depth of incision of the upper gravel lag in surface/ T1 exposures in Matzhiwin Creek and the scour channels found in the area, they probably formed contemporaneously.

At site 20 (fig.3.8) the upper gravel lag resulting from surface scouring is overlain by ponded sediments which formed on the prairie surface during early postglacial times. Similar ponded sediments overlying a gravel lag have also been observed in Onetree Creek and Little Sandhill Creek (Campbell and Evans 1990;Campbell *et al*.1993).

During the later stages of drainage, flow became increasingly channelised resulting in deep incision through the glacial flute/ remnant ridge in several places. The precursor of Matzhiwin Creek initially flowed towards the east incising the glacial flute to a depth of 700m asl as well as flowing to the north into the early Red Deer River channel (fig.3.1). Where meltwaters breached the flute/ remnant ridge, flow competence was abruptly dissipated resulting in rapid deposition of sediment forming the lobe feature (figs.3.1 and 3.2). The lower gravel lag derived from the underlying diamicton observed upstream at site 15 (fig.3.8) may reflect this incision episode which cut through the flute/ remnant ridge further downstream. The gravel lag overlying diamicton at site 15 is located at an elevation of 702m asl or approximately 15m below the prairie surface. Scour channels located either side of the depositional lobe (fig.3.1) are found at a similar elevation, approximately 700m asl (fig.3.17b). Therefore, due to the similar depth of incision upstream at site 15 (fig.3.8) and downstream through the flute/ remnant ridge (fig.3.17b), they are interpreted to have formed during the same incision phase. Deep incision through the flute/ remnant ridge also occurred in the ancestral Red Deer River. Enhanced incision may have resulted from either increasingly channelised flows in these early spillways or from increased volumes of meltwaters derived from the northwest.

Broad valley incision and lateral scouring followed in the Red Deer River shortly after extensive surface scouring by meltwaters (Bryan *et al*.1987). Broad surfaces in Dinosaur Provincial Park and upper bedrock benches along the Red Deer River at 690-680m asl formed during this broad valley stage (Bryan *et al*.1987). The broad valley incision in the Red Deer River was followed by a period of narrow, deep incision to a depth of approximately 20-40m below the present stream bed (MacPherson 1968) (fig.3.17c). Cross section B-B' (fig.3.10c) illustrates this phase of deep incision in the

Red Deer valley (Tokarsky 1986). The extensive bedrock bench found in the downstream reach of Matzhiwin Creek (fig.3.4) is located at an elevation of 690m asl and may correspond with the broad valley incision observed in the Red Deer River. However, this bedrock bench corresponds stratigraphically with the elevation of Empress Formation gravels which outcrop at site 17 (fig.3.8). The preglacial gravel conglomerate at this elevation may have formed a relatively resistant barrier to incision enhancing lateral migration in the channel and forming an extensive bedrock surface at approximately 690m asl in the downstream reach of Matzhiwin Creek.

Deep incision followed in the downstream reach of Matzhiwin Creek in response to local baselevel changes associated with downcutting of the Red Deer River. At this time, the Red Deer River was still receiving large volumes of meltwaters from upstream whilst around the study area proglacial lake drainage and the formation of modern drainage basins resulted in decreased flows and slowed the incision rates in the small tributary creeks. Due to the differences in incision rates between tributary and trunk streams, tributary creeks developed steep convex-up long profiles. Deep incision in Matzhiwin Creek near the confluence with the Red Deer River steepened the creek's gradient and resulted in flow reversal in the formerly eastward flowing tributary channel which cuts through the glacial flute (fig.3.1).

It is proposed that during the early postglacial evolution of Matzhiwin Creek an aggradational phase occurred. In many T2 and T3 exposures the valley fill is composed of medium-grained, well sorted, planar-crossbedded sands which overlie the gravel lag at exposure 15 and directly overlies diamicton in numerous other exposures (fig.3.8). In places the valley fill is overlain by T2 and T3 alluvium with an erosional boundary. The valley fill was only observed in the upstream reach of the creek, deep

incision further downstream has evidently removed the valley fill. The cause of this aggradation is unknown but may relate to the waning stages of a high discharge event during early postglacial drainage or baselevel changes. An early aggradational phase is also observed in the Red Deer River during the early postglacial prior to deep incision resulting in a sand/ gravel valley fill (MacPherson 1968). The cause of deposition is unknown but may relate to ice readvance or glacioisostatic adjustments. Aggradation of the sand fill observed upstream in Matzhiwin Creek may have been triggered by aggradation of the sand and gravel fill in the Red Deer River. The lack of any dating control makes it impossible to assess whether or not these alluvial fills are stratigraphically related or to date the time of deposition.

Similar deposits to the valley fill observed in the upstream reach of Matzhiwin Creek underlying T2 and T3 alluvium (fig.3.7) were observed in an irrigation ditch to the south along highway 36 (fig.3.1). These sands are found at an elevation of approximately 710m asl and correspond stratigraphically with the valley fill in Matzhiwin Creek which is found between 702-710m asl (fig.3.8). The sands found in the irrigation ditch have been tentatively interpreted as early Holocene by thermoluminescence dating (Campbell pers. comm.) and may have originally been derived from a large delta system to the west of Matzhiwin Creek southeast of Crawling valley (fig.3.1). It is possible that the valley fill and the sand deposits found to the south of Matzhiwin Creek relate to the same event/ events during early postglacial drainage.

Deep incision in the downstream reach of Matzhiwin Creek in the early postglacial, triggered by rapid downcutting in the Red Deer River, stimulated mass movements along the valley sides. Extensive mass movements are evident in the central reach of the valley (fig.3.4) and in the tributary which cuts through the flute/ remnant ridge.

Holocene evolution

A period of aggradation followed in the Red Deer River valley depositing fine grained alluvium (MacPherson 1968). The timing and cause of this event are unknown. MacPherson (1968) suggested aggradation resulted from glacioisostatic adjustments though Bryan *et al.*(1987) attributed the aggradation to an increased sediment load to the Red Deer River during badland formation between 9.0-6.0 ka BP, combined with a decreased discharge following Laurentide ice retreat to the north. It is possible that both processes were involved.

In the upstream reach of Matzhiwin Creek a period of incision into the older valley fill, which overlies the diamicton, is recognised. This was followed by aggradation of T2 alluvium. The timing of incision and the subsequent aggradational phase which formed the T2 surface are unknown. However, due to the large, areal extent of the T2 surface (fig.3.5) and the numerous palaeochannels which have incised into its surface, it is likely that its formation was prolonged. Radiocarbon dates obtained from material retrieved from terrace alluvium in Threehills Creek (located further upstream) and Onetree Creek suggest a period of aggradation occurred between about 3.0-2.0 ka BP (Rains pers.comm.;Campbell *et al.*1993). It is possible that T2 aggradation in Matzhiwin Creek occurred around the same time, reflecting widespread aggradation in tributary creeks though there is no evidence for this at present. As the timing is unknown the cause of T2 aggradation is difficult to determine; it may relate to baselevel changes triggered by the aggradational event in the Red Deer River or a climatic shift towards increasingly arid conditions in the mid Holocene (Vance *et al.*1992). Increased aridity would have reduced discharge and possibly increased sediment load to the channel causing aggradation (Knox 1983).

In the downstream reach of Matzhiwin Creek a period of alluvial fan deposition is evident. Fan deposits were also

observed by O'Hara and Campbell (1993) in the lower Falcon valley and are suggested to reflect mid Holocene aridity and an increased sediment yield to the valley floor sometime around 6.0 ka BP. If the alluvial fan deposits in Matzhiwin Creek formed at about that time then deep incision of the downstream reach of Matzhiwin Creek must have already reached its maximum depth as the fan deposits are rarely located more than 8m above the present stream bed. This suggests that the majority of incision in Matzhiwin Creek was completed prior to 6.0 ka BP for the downstream reach and was followed by a period of aggradation and alluvial fan formation. It is possible that T2 aggradation was active during deposition of alluvial fans sometime during the mid Holocene and after major valley incision was completed. Deposition of fan material in the downstream reach would have raised baselevel locally and may even have triggered T2 aggradation upstream.

According to O'Hara and Campbell (1993) fan deposition was active until around 5.0 ka BP when a thick layer of aeolian sands were deposited. This timing is based on a thermoluminescence date of 5.4 ka+/-800 BP (ALPHA-2074) retrieved from near the base of aeolian sediments found extensively in Dinosaur Provincial Park (Bryan *et al.*1987).

A further period of incision followed in the Red Deer River, trenching the fine grained alluvial fill (MacPherson 1968). No dates exist for this erosional event though Bryan *et al.*(1987) suggested that deposition of aeolian sediments increased infiltration rates on badland surfaces and drastically reduced sediment load to the Red Deer River. Truncation of alluvial fans in the lower Falcon valley (O'Hara and Campbell 1993) and in Matzhiwin Creek suggests that a phase of regional incision resulted from baselevel changes associated with the downcutting in the Red Deer River. A period of incision is also apparent in the upstream reach of Matzhiwin Creek with 2-3m of downcutting from the T2 surface (fig.3.8). The timing of T2 incision is unknown

but must have occurred prior to 2.0 ka BP when T3 aggradation was underway (fig.3.8). Incision of T2 alluvium may correlate with incision of fan material downstream which is suggested to have resulted from baselevel changes in the Red Deer River. Vance *et al.*(1992) noted a trend towards increasingly wetter conditions post 4.0 ka BP in southern Alberta. Incision of T2 alluvium may have been climatically controlled, associated with wetter conditions between about 4.0 - 2.0 ka BP and independent of baselevel changes further downstream.

A further period of channel aggradation began around 1.8 ka BP and was still active up until 1.3 ka BP, forming the T3 surface in the upstream reach of Matzhiwin Creek. Bone-derived radiocarbon dates which range from 1.3 - 1.8 ka BP were obtained from T3 alluvium approximately 2m above the present stream bed and 20m below the prairie surface (fig.3.8). The T3 surface is not as extensive as the T2 surface and overlies the older valley fill in exposures 10 and 15 (figs.3.7 and 3.8). Deeper incision at sites 18 and 19 has removed the older valley fill and T3 alluvium has been inset almost to the underlying bedrock.

Channel aggradation occurred in Onetree Creek and Little Sandhill Creek between 2.9-1.3 ka BP (Campbell and Evans 1990;Campbell *et al.*1993). The cause of widespread valley aggradation in the late Holocene between 2.0 - 1.0 ka BP is unknown though the two most likely trigger mechanisms are baselevel change and climate. A trend towards increasingly arid conditions is noted by Vance *et al.*(1992) between 2.0-1.0 ka BP during the Medieval Warm Phase.

T3 aggradation was followed by 2-4m of incision to the present stream bed sometime after 1.3 ka BP in the upstream reach of Matzhiwin Creek (fig.3.8). Incision also occurred in Little Sandhill Creek and Onetree Creek between 1.3 ka BP and 0.5 ka BP (Campbell and Evans 1990;Campbell *et al.*1993). The cause of incision is unknown though one obvious explanation is a climatic shift towards wetter conditions

during the well documented Little Ice Age around 0.6 - 0.3 ka BP (Luckman and Osborn 1977;Gardner and Jones 1985;Vance *et al*.1992).

Thick deposits of aeolian sediments overlie all 3 terraces in the upstream reach of Matzhiwin Creek. A $^{14}C$ date of 1550+/-60 ka BP was retrieved from a bone within a palaeosol underlying aeolian deposits at site 20 (fig.3.8). The date suggests a period of active aeolian deposition post 1.5 ka BP and is confirmed by the aeolian sediments overlying T3 alluvium (fig.3.8). The aeolian deposits contain up to four palaeosols reflecting periods of stability and soil formation. It is unknown whether the post 1.5 ka BP deposition of aeolian sediments was triggered as a result of increasing aridity during the Medieval Warm Phase or whether deposition has been relatively continuous during the Holocene.

Vreeken (1989) suggested that aeolian sediments overlying the Lethbridge moraine in southern Alberta were deposited almost immediately after lake drainage in the area, around 11.2 ka BP. Deposition continued throughout the Holocene with alternating periods of stability and soil formation. Aeolian sediments in Matzhiwin Creek deposited post 1.5 ka BP support this conclusion. Large areas of sand dune deposits to the north of Matzhiwin Creek and steep, unvegetated valley sides resulting from deep Holocene incision by rivers, provide ideal local source areas for the aeolian material. Periods of aeolian deposition may reflect inherently unstable dune conditions or recurrent drought and or fire in the area during the postglacial period. The impact of bison herds on the prairie surface and their destruction of vegetation may have also triggered phases of aeolian activity in the past.

### 3.7 Conclusion

During the early postglacial evolution of Matzhiwin Creek deep incision occurred through the glacial flute/ remnant ridge (fig.3.1) and the upper T1 surface formed in the upstream reach due to scouring by easterly draining meltwaters.

Incision in the Red Deer River followed (MacPherson 1968) triggering deep incision in the downstream reaches of tributary creeks. Over 70m of downcutting occurred in the downstream reach of Matzhiwin Creek near the confluence with the Red Deer River (fig.3.4) producing a characteristic convex-up long profile and flow reversal in the main tributary through the glacial flute/ remnant ridge. An extensive bedrock bench at 690m asl in the downstream reach may correlate with upper benches in the Red Deer River which formed during the broad valley stage (Bryan *et al*.1987), or may represent structural control from Empress Formation deposits which outcrop upstream at approximately the same elevation (fig.3.4).

Deep incision in the downstream reach was completed by the mid Holocene when alluvial fans formed on the valley floor as the region became increasingly arid (Vance *et al*.1992). During the mid to late Holocene two distinct aggradational phases are evident in the upstream reach of the creek in the form of T2 and T3 alluvium (fig.3.4). Both T2 and T3 alluvium have incised into an older valley fill which is suggested to have been deposited in the early postglacial period. T2 aggradation probably spanned a considerable length of time though its exact age is unknown. T3 aggradation was active between approximately 1.8 - 1.3 ka BP and corresponds with aggradational phases in Onetree Creek and Little Sandhill Creek (Campbell and Evans 1990;Campbell *et al*.1993). The cause of T2 and T3 aggradation is unknown but most likely relates to baselevel or climate change. Incision of the T2 surface is suggested

to have occurred sometime between 4.0 - 2.0 ka BP and may correspond with the incision phase which truncated the alluvial fans downstream. Truncation of fan deposits in the lower Falcon valley suggests regional incision at this time in response to downcutting in the Red Deer River (O'Hara and Campbell 1993). T3 aggradation corresponds with increasing aridity during the Medieval Warm Phase around 1.5 ka BP (Vance *et al*.1992). Incision of T3 alluvium occurred sometime after 1.3 ka BP and may reflect wetter conditions associated with the Little Ice Age between 0.6 - 0.3 ka BP (Vance *et al*.1993). Incision in Onetree Creek and Little Sandhill Creek also occurred between 1.3 - 0.3 ka BP (Campbell and Evans 1990;Campbell *et al*.1993).

The chronology of Matzhiwin Creek suggests downcutting was the dominant process up until the mid Holocene after which minor episodes of aggradation and degradation occurred. The timing of aggradation and incision phases in Matzhiwin Creek and other local basins reveal a partial overlap suggesting the influence of an external variable in triggering widespread changes in stream behaviour. The two dominant influences on the evolution of Matzhiwin Creek are climate and baselevel change. Distinct phases of aggradation and incision occurred in the Red Deer River in the postglacial period (MacPherson 1968) which must have had a major impact on channel behaviour in downstream reaches of the tributary creeks. How far upstream such a baselevel change will have an effect is uncertain. During the early to mid Holocene, deep incision in the Red Deer River was the dominant influence on channel behaviour in Matzhiwin Creek. Deep incision occurred in the downstream reach and a convex-up long profile formed. During the mid to late Holocene periods of aggradation and incision may be explained by both climate and baselevel changes; the dominant influence is difficult if not impossible to identify. A climate change to increasingly arid conditions may increase the sediment load to the Red Deer River resulting in aggradation and a

baselevel change, triggering aggradation in tributary creeks. Therefore, in some instances, aggradation in tributaries may be a combination of both climate and baselevel change. Even if a particular event can be identified as being triggered by a climate change it is unclear as to exactly how climate change effects channel processes due to the complex interactions between discharge, sediment load and vegetation (McDowell 1983). If climate has been a dominant influence on channel behaviour in Matzhiwin Creek it appears that episodes of channel aggradation occurred during warm/ arid conditions and episodes of incision occurred during cool/moist conditions.

Matzhiwin Creek has incised, at least partly, into the preglacial Calgary valley (Stalker 1961;Tokarsky 1986). The preglacial Empress Formation gravels and sands and thick exposures of diamicton in Matzhiwin Creek show the partial form of this preglacial valley. However, Empress Formation deposits were not observed in the downstream reach of Matzhiwin Creek between highway 36 and the confluence with the Red Deer River (fig.3.1). Interpretation of the subsurface bedrock topography (fig.3.3) suggests that the preglacial Calgary valley trends northeastward and therefore the downstream reach of Matzhiwin Creek has not incised into the preglacial valley. A distinctive knickpoint is apparent in the long profile at site 17 (figs.3.4 and 3.8) where Empress Formation gravels and sands outcrop. The gravel conglomerate inhibits stream incision and may enhance rates of lateral stream migration.

Radiocarbon dated material obtained from T3 alluvium, and from a palaeosol below aeolian sediments, suggest that aeolian activity has been active since at least 1.5 ka BP. These findings support the work of Vreeken (1989) which shows that aeolian activity has been continuous in the area with episodic periods of stability and soil formation.

### 3.8 Bibliography


Alberta Research Council 1970. Bedrock topography of the Medicine Hat area, NTS 72L, Alberta, 1:250 000.

Alberta Environment 1991. Computer generated water well driller's report form. Well I.D 155678, 154784 and 160097.

Bacon, C.R. 1983. Eruptive history of Mount Mazama and Crater Lake caldera, Cascade Range, U.S.A. Journal of Volcanology and Geothermal Research, **18**: 57-115.

Beaty, C.B. 1976. Landscapes of southern Alberta- a regional geomorphology. University of Lethbridge Production Services.

Bryan, R.B. and Campbell, I.A. 1980. Sediment entrainment and transport during local rainstorms in the Steveville Badlands, Alberta. Catena, **7**. 51-65.

Bryan, R.B, Campbell, I.A. and Yair, A. 1987. Postglacial geomorphic development of the Dinosaur Provincial Park badlands, Alberta. Canadian Journal of Earth Sciences, **24**: 135-146.

Campbell, I.A. and Evans, J.A. 1990. Glaciotectonism and landsliding in Little Sandhill Creek, Alberta. Geomorphology, **4**: 19-36.

Campbell, I.A, Rains, R.B, Shaw, J. and Evans, J.A. 1993. Glacial and Holocene Geomorphology of the Alberta Prairies. A Field Guide for the Third International Geomorphology Conference, Hamilton, Ontario.

Christiansen,E.A. 1979. The Wisconsin deglaciation of southern Saskatchewan and adjacent areas. Canadian Journal of Earth Sciences, **16**: 913-938.

Christiansen, E.A. 1992. Pleistocene stratigraphy of the Saskatoon area, Saskatchewan, Canada: An update. Canadian Journal of Earth Sciences, **29**: 1767-1778.

DeLugt, J. and Campbell, I.A. 1992. Mass movements in the badlands of Dinosaur Provincial Park, Alberta, Canada. Catena Supplement **23**. 75-100.

Donnelly, L.M. 1990. A study of longitudinal profiles of tributaries of the North Saskatchewan River. B.Sc (Honours) thesis, University of Alberta, Edmonton, Alberta.

Dyke, A.S. and Prest, V.K. 1987: Late Wisconsin and Holocene history of the Laurentide ice sheet. Geographie physique et Quaternaire, **LXI**: 237-263.

Environment Canada 1982. Canadian Climate Normals, 1951-1980. Canadian Govt. Pub. Centre, Canada.

Evans, J.A. 1991. A gravel/ diamicton lag on the southern Albertan prairies, Canada: Evidence of bed armouring in early deglacial sheet-flood/ spillway courses. Geological Society of America Bulletin, **103**: 975-982.

Evans, J.A. and Campbell, I.A. 1992. Glacial and postglacial stratigraphy of Dinosaur Provincial Park and surrounding plains, southern Alberta, Canada. Quaternary Science Reviews, **11**: 535-555.

Gardner, J.S. and Jones, N.K. 1985. The Neoglacial Advance of Boundary Glacier, Banff National Park, Alberta. Canadian Journal of Earth Sciences, **22**: 1753-1755.

Knox, J.C. 1983. Responses of river systems to Holocene climates. **In** Late Quaternary Environments of the U.S. **Edited by** W.E Wright. University of Minnesota Press, Minneapolis: 26-41.

Koster, E.H. 1984. Sedimentology of a foreland coastal plain: Upper Cretaceous Judith River Formation at Dinosaur Provincial Park. 1984 Fieldtrip Guidebook, Canadian Society of Petroleum Geologists.

Luckman, B.H and Osborn, G.D. 1977. Holocene glacier fluctuations in the middle Canadian Rocky Mountains. Quaternary Research, **11**: 52-77.

MacLean, J.R. 1971. Stratigraphy of the Upper Cretaceous Judith River Formation in the Canadian Great Plains. Saskatchewan Research Council, Geology Division. Report 11.

MacPherson, H.J. 1968. Historical development of the lower Red Deer Valley, Alberta. The Canadian Geographer, **12**: 227-240.

McDowell, P.F. 1983. Evidence of stream response to Holocene climatic change in a small Wisconsin watershed. Quaternary Research, **19**: 100-116.

O'Hara, S.L. and Campbell, I.A. 1993. Holocene geomorphology and stratigraphy of the lower Falcon Valley, Dinosaur Provincial Park, Alberta, Canada. Canadian Journal of Earth Sciences, **30**: 1846-1852.

Patton, P.C. and Schumm, S.A. 1975. Gully erosion, northwestern Colorado: A threshold phenomenon. Geology, **3**: 88-90.

Rains, R.B. and Welch, J.E. 1988. Out-of-phase Holocene terraces in part of the North Saskatchewan River basin, Alberta. Canadian Journal of Earth Sciences, **25**: 454-464.

Rains, R.B, Burns, J.A. and Young, R.R. 1994. Postglacial alluvial terraces and an incorporated bison skeleton, Ghostpine Creek, southern Alberta. Canadian Journal of Earth Sciences, **31**: 1501-1509.

Rutherford, R. 1937. Saskatchewan gravels and sands in central Alberta. Royal Society of Canada Transactions, IV: Series 3, **31**: 81-95.

Schoenfeld, D.A. and Hammer, M.J. 1991. The determination of gross and effective drainage areas in the prairie provinces. Agriculture Canada, Prairie Farm Rehabilitation Administration, Addendum #5, Hydrology Report #104. Regina, Saskatchewan.

Schumm, S.A. 1973. Geomorphic thresholds and complex response of drainage systems. **In** Fluvial Geomorphology. **Edited by** M.Morisawa. State University of New York, pp. 299-310.

Stalker, A.MacS. 1968. Identification of Saskatchewan gravels and sands. Canadian Journal of Earth Sciences, **5**: 155-163.

Stalker, A.MacS. 1961. Buried valleys in central and southern Alberta. Geological Survey of Canada, Paper 60-32.

Tokarsky, O. 1986. Hydrogeologic cross-sections of southern Alberta. Earth Sciences Division, Alberta Environment, Edmonton, Alberta.

Vance, R.E, Mathewes, R.W. and Clague, J.J. 1992. 7,000 year record of lake-level change on the northern Great Plains: A high resolution proxy of past climate. Geology, **20**: 879-882.

Vreeken, W.J. 1989. Late Quaternary deposits in the Lethbridge area, Alberta. Canadian Journal of Earth Sciences, **26**: 551-560.

Whitaker, S.H. and Christiansen, E.A. 1972. The Empress Group in southern Saskatchewan. Canadian Journal of Earth Sciences, **9**: 353-360.

## 4.0 Conclusion

Alluvial chronologies presented in chapters 2 and 3 have revealed information on the timing and the nature of fluvial adjustments in central and southern Alberta since deglaciation. Large, easterly flowing rivers such as the North Saskatchewan and Red Deer began incising their valleys in the immediate postglacial period following Laurentide ice retreat to the northeast and the drainage of proglacial lakes (St-Onge 1972). Rapid rates of stream downcutting during the early postglacial were due to high discharges and the highly erodible nature of the underlying bedrock, combined with the effects of isostatic recovery (MacPherson 1968;Rains and Welch 1988). Upper terraces along the North Saskatchewan River (Edmonton region), Bow River (Calgary region) and the lower Red Deer River reflect temporary baselevel changes associated with Laurentide ice front positions and proglacial lake margins during deglaciation (MacPherson 1968;Stalker 1968;Rains and Welch 1988).

In the early postglacial period tributary streams formed initially as large gullies or narrow spillways. Tributary streams were unable to downcut at the same rate as the rapidly incising trunk streams due to their smaller drainage basin sizes and discharges. As a result, tributary streams developed steep, convex-up profiles in downstream reaches near the confluence with trunk streams (Rains and Welch 1988;O'Hara and Campbell 1993;Rains *et al.*1994). In Matzhiwin Creek over 70m of downcutting occurred in the downstream reach near the confluence with the Red Deer River. Baselevel change associated with rapid downcutting in trunk streams was therefore the dominant control on downstream reaches of tributary streams during the early postglacial period. Deep incision in downstream reaches did not favour alluvial terrace formation/ preservation in Matzhiwin or Ghostpine Creek (Rains *et al.*1994).

Early postglacial scouring by meltwaters resulted in

the formation of the upper terrace surface in Matzhiwin Creek and a gravel lag, derived from eroded till, close to the prairie surface (Evans 1991). At one site the T1 gravel lag is overlain by ponded sediments, similar to those identified by Campbell and Evans (1990) which were deposited around 9.1ka BP.

A distinctive, paired bedrock bench at 690m asl in the downstream reach of Matzhiwin Creek most likely formed during the early postglacial evolution and may relate to upper benches at a similar elevation in the valley of the Red Deer River (Bryan *et al*.1987). The bench may also, however, reflect structural control. In the upstream reach of Matzhiwin Creek a distinctive knickpoint marks the outcrop of the Empress Formation gravels and sands. This preglacial gravel conglomerate prevents easy stream incision and possibly enhances rates of lateral stream migration.

Deep incision (ca.70m) in the downstream reach of Matzhiwin Creek was completed by the mid Holocene when alluvial fan deposits formed along the valley sides. Similar deposits in the lower Falcon valley, Dinosaur Provincial Park, were interpreted as being associated with more arid conditions in the mid Holocene (O'Hara and Campbell 1993). Truncation of alluvial fan deposits during the mid to late Holocene in Matzhiwin Creek and the lower Falcon valley may relate to a baselevel change associated with downcutting in the Red Deer River (MacPherson 1968;Bryan *et al*.1987;O'Hara and Campbell 1993), or a climatic change to wetter conditions post 4.0ka BP (Vance *et al*.1993).

Upstream reaches of tributary valleys contain various alluvial terrace remnants (Rains and Welch 1988;Rains *et al*.1994) which provide evidence of postglacial cycles of stream aggradation and incision. Radiocarbon dated materials obtained from terrace alluvium suggest widespread aggradational phases occurred between about 3.2-2.0ka BP and 1.8-0.3ka BP in Onetree, Ghostpine, Little Sandhill, Matzhiwin and Whitemud creeks (Rains and Welch 1988;Campbell

and Evans 1990;Campbell *et al.*1993;Rains *et al.*1994). Phases of incision occurred between 2.0-1.8ka BP and post 0.3ka BP. The widespread nature of in-phase aggradation and incision suggests the strong influence of a large-scale climate change on tributary creeks in central and southern Alberta. Periods of stream incision in the study area between 2.0-1.8ka BP and post 0.3ka BP correlate with periods of widespread stream incision which occurred in selected U.S and European rivers (Brakenridge 1980).

Incision phases of the study area coincide with cool/ moist periods (Vance *et al.*1993). Cyclic changes in upper atmospheric circulation and intensified meridionality possibly result in cool/ moist phases and increase the frequency of floods of magnitudes capable of significant stream incision (Brakenridge 1980;Knox 1983). Slow floodplain aggradation, followed by brief periods of incision, appear to have occurred during the mid to late Holocene in Whitemud, Onetree and Matzhiwin Creeks (Rains and Welch 1988; Campbell *et al.*1993).

The regional evidence suggests the importance of large-scale climate change on stream behaviour in the mid to late Holocene, though the processes are unclear. The out-of-phase relationship between the terraces of the North Saskatchewan River in the Edmonton region and those of its tributary creeks indicates the importance of drainage basin size. All four terraces in Whitemud and Strawberry creeks formed over approximately the same time span as the youngest terrace in the North Saskatchewan River (Rains and Welch 1988). Therefore, mid to late Holocene climatic variations appear to have had little effect on the North Saskatchewan River. Localised, high intensity, convectional storms may have a major impact on small tributary basins but a minimal effect on larger drainage basins such as the North Saskatchewan. However, the unique characteristics of each drainage basin will determine the exact timing and response of a fluvial system to a specific climate change (Wolman and Gerson

1978).

In Matzhiwin Creek aeolian sediments cap the alluvial terrace surfaces in the upstream reach. Radiocarbon dated materials obtained from a palaeosol and terrace alluvium below aeolian deposits indicate that wind deposition was active around 1.8-1.3ka BP in this area. Multiple palaeosol horizons in aeolian deposits suggest that aeolian deposition has alternated with periods of stability and soil formation since at least 1.8ka BP.

In conclusion, baselevel change associated with rapid downcutting of trunk rivers and the possible effects of isostatic recovery were initially important controls on tributary stream behaviour. During the mid to late Holocene alluvial chronologies indicate climatic changes have strongly influenced widespread periods of stream aggradation and incision in smaller tributary creeks in central and southern Alberta.

## 4.1 Bibliography


Brakenridge, G.R. 1980. Widespread episodes of stream erosion during the Holocene and their climatic cause. Nature, **283**: 655-656.

Bryan, R.B, Campbell, I.A. and Yair, A. 1987. Postglacial geomorphic development of the Dinosaur Provincial Park badlands, Alberta. Canadian Journal of Earth Sciences, **24**: 135-146.

Campbell, I.A. and Evans, J.A. 1990. Glaciotectonism and landsliding in Little Sandhill Creek, Alberta. Geomorphology, **4**: 19-36.

Campbell, I.A, Rains, R.B, Shaw, J. and Evans, J.A. 1993. Glacial and Holocene Geomorphology of the Alberta Prairies. A field guide for the third international geomorphology conference. University of Alberta.

Evans, J.A. 1991. A gravel/ diamicton lag on the southern Albertan prairies, Canada: Evidence of bed armouring in early deglacial sheet-flood/ spillway courses. Geological Society of America Bulletin, **103**: 975-982.

Knox, J.C. 1983. Responses of river systems to Holocene climates. In Late Quaternary Environments of the U.S. Ed. by W.E Wright. Univ. of Minnesota Press, Minneapolis: 26-41.

MacPherson, H.J. 1968. Historical development of the lower Red Deer Valley, Alberta. The Canadian Geographer, **12**: 227-240.

O'Hara, S.L. and Campbell, I.A. 1993. Holocene geomorphology and stratigraphy of the lower Falcon Valley, Dinosaur Provincial Park, Alberta, Canada. Canadian Journal of Earth Sciences, **30**: 1846-1852.

Rains, R.B. and Welch, J.E. 1988. Out-of-phase Holocene terraces in part of the North Saskatchewan River basin, Alberta. Canadian Journal of Earth Sciences, **25**: 454-464.

Rains, R.B, Burns, J.A. and Young, R.R. 1994. Postglacial alluvial terraces and an incorporated bison skeleton, Ghostpine Creek, southern Alberta. Canadian Journal of Earth Sciences, **31**: 1501-1509.

Stalker, A.Mac. 1968. Geology of the terraces at Cochrane, Alberta. Canadian Journal of Earth Sciences, **5**: 1455-1466.

St-Onge, D.A. 1972. Sequence of glacial lakes in north-central Alberta. Geological Survey of Canada, Bulletin 213.

Vance, R.E, Mathewes, R.W. and Clague, J.J. 1992. 7,000 year record of lake-level change on the northern Great Plains: A high resolution proxy of past climate. Geology, **20**: 879-882.

Wolman, M.G. and Gerson, R. 1978. Relative scales of time and effectiveness of climate in watershed geomorphology. Earth Surface Processes and Landforms, **3**: 189-208.